THE

# ECONOMY OF NATURE

EXPLAINED AND ILLUSTRATED

ON THE

PRINCIPLES

OF

MODERN PHILOSOPHY.

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### CHAPTER I.

### * OF SALTS IN GENERAL.

*Definition of Salts.—Salts ſimple and compound.—What are called ſimple Salts are in reality compound Bodies.—Oxygenous Principle.*

THOSE ſubſtances are denominated ſalts which are fuſible, volatile, ſoluble † in water, not inflammable, and ſapid when applied to the tongue. The moſt ſimple ſtate of ſalts, is a maſs, white, brittle, and in ſome degree tranſparent. Salts in certain

* This part of the work will neceſſarily be in ſome meaſure chemical; but it is only by chemical proceſs that we can reach the conſtituent particles of natural bodies. The reaſon of this arrangement will be obvious. The object of this book is to treat of the ſtructure of the earth; but it is neceſſary to be firſt informed concerning the different matters of which it is compoſed.

† The diſtinction between ſolution and mixture has been already ſtated; but it may not be improper to remind the reader, that in ſolution the body which was ſolid is ſo completely in union with the fluid or menſtruum, that the compound is completely tranſparent, though not always colourleſs. Common ſalt, for inſtance, with water, makes a colourleſs ſolution; but

certain degrees of heat are fluid and transparent, like oil. They differ in their degree of fusibility and volatility. Some assume the form of vapour in the ordinary temperature of the atmosphere, others in a great degree of heat remain fixed. Previous to treating of the particular substances of this class, it will be proper to make a few observations on the formation of salts in general. Salts are either simple or compound. Simple salts are distinguished into alkalis and acids; and from the union of an acid and an alkali are produced compound salts, which are also called neutral, because by this combination the characteristic properties both of the acid and alkali are lost, and a new body is formed, which is extremely inert, in comparison with the two substances of which it is composed. Several of the earths and some of the metals are also capable of being united with acids, and the compound forms a salt more or less perfect.

Alkalis and acids, at the time they obtained the name of simple salts, were supposed to be really such; modern discoveries, however, have now led to a different conclusion, and left no reason to doubt that all the acids, and at least one of the alkalis, are compound bodies. The doctrine of the formation of acids is now fully elucidated; the

but blue or green vitriol makes a blue or green solution with water. A mixture on the contrary is always muddy, and if left to stand, a sediment will be deposited. The point of *saturation* is when the fluid will hold no more of the solid body in clear solution, but *precipitates* it, or lets it fall to the bottom.

processes

processes of combustion, and of the calcination of metals, which were formerly attributed to the expulsion of an imaginary substance, called phlogiston; are now proved to be only the formation of acids; or the union of the principle of acidity or oxygen contained in the atmosphere, with substances, the particles of which have, in certain circumstances, a stronger attraction for that principle, than it has for the matter of heat. The chief circumstance which favours the union of the principle of acidity, which is also called by the French chemists oxygen, with other bodies, is a proper degree of heat; which, by removing the particles of bodies further from each other, diminishes their attraction, and allows room for the entrance of air into their interstices. In the calcination of metals, and in combustion, the oxygen gas of the atmosphere is decomposed, and while the base is attracted by the inflammable substance or metal, the matter of heat is disengaged, and becomes sensible. Bodies, however, may be acidified or oxygenated without being exposed to the air; and this is performed by placing them in contact with bodies which are already united with oxygen, but which have a weaker attraction for that principle than the body which is to be acidified. It is upon this principle that metals are deprived of oxygen, or reduced to the metallic state, by heating them in contact with charcoal, tallow, &c. In this case the inflammable substance having a stronger attraction for oxygen than the metal has, becomes oxygenated; while the metal, by being deprived of this principle, is reduced to the me-

tallic ſtate. Metals and combuſtible bodies may alſo be oxygenated in the humid way, by ſubmitting them to the action of acids. In this proceſs the acid furniſhes the oxygen, and is therefore decompoſed. The oxygenation of minerals in the bowels of the earth is probably chiefly effected by the decompoſition of water, which is a compound of hydrogen and oxygen. A proceſs of this kind is continually carried on before our eyes; the ruſt which iron acquires by being expoſed to damp air is an oxygenation of that metal. Other metals, however, have leſs affinity with the principle of acidity, and this is remarkably the caſe with the perfect metals, platina, gold, and ſilver, which therefore do not become ruſted by expoſure to air.

In treating of ſalts, I ſhall firſt give an account of the alkalis, next of the acids, and laſtly of their combinations, or the neutral ſalts. I ſhall defer ſpeaking of the earthy and metallic ſalts till the earths and metals are deſcribed.

CHAP.

# CHAP. II.

## ALKALIS.

*Mineral fixed Alkali; where found.—Vegetable fixed Alkali; how obtained.—Use of the fixed Alkalis in the Arts.—Use of Alkalis in making Glass.—Process of making Soap.—Volatile Alkali; how obtained; a compound Body.—Alkaline Air.*

MINERAL fixed alkali, soda or natron, is the salt which is found recorded in ancient history under the name of nitre. It is said to be found in Egypt in tolerably pure crystals, and also in Persia, where it appears in a form resembling that of hoar frost. Even in Europe it is found in small quantities in mineral springs, and also on the surface of new walls, in the form of a damp and dewy efflorescence. In a compound state it is found in abundance; it makes half the weight of common salt, and is also occasionally found naturally combined with other acids. The mineral alkali cannot be obtained from the native salts containing it, without great labour and expence: what is used in the arts is procured by the incineration of certain plants growing near the sea-side. The crude mineral alkali in commerce is called soda or barilla. Alkalis are either mild or caustic; the latter is their most simple state, as when mild they are united with the carbonic acid, with which they form a

kind of neutral salt. Though the carbonic acid has less affinity with the alkalis than any other acid, yet it is difficult to separate it entirely. The usual method of accomplishing it is to dissolve the mild alkali in water, to add to this solution some quick-lime, and then to filtrate the liquor, and evaporate it in closed vessels; the saline substance left after evaporation is an alkali almost entirely deprived of carbonic acid. This process is founded on the greater attraction which the carbonic acid has for quick-lime than for the alkalis.

The VEGETABLE fixed alkali, pot-ash or kali, agrees in several circumstances with the former. It is acrid when applied to the tongue, requires as great a degree of heat to melt it; and in a very strong heat flies off totally in vapour. It differs from the fossil alkali in having a much stronger attraction for water. This alkali may be crystallized, but not so easily as the fossil. Little of the vegetable alkali has been found in a state of nature, and that only as entering into the composition of nitre. It is obtained in considerable quantities from the ashes of almost all land vegetables, by infusing them in water; the liquid, when strained from the dregs, will then contain the salt in a state of solution, and by evaporation we obtain the alkali in a solid form. It is also easily obtained from a substance called tartar, which is deposited by wine. The properties and uses of the vegetable alkali are very similar to those of the mineral.

The fixed alkalis are employed in several of the arts, and particularly in that of making glass; for though

though many fubftances will fufe the vitrifiable earths, and reduce them to a kind of glafs, the alkalis are found the moft effectual and convenient.

In the foap manufactory alfo the alkalis are a principal and effential ingredient. Common foap is indeed a combination of fixed alkali in a cauftic ftate with fat and oily matters. A very fine fpecies of foap is formed by the union of mineral alkali with olive-oil, or oil of fweet almonds. In the making of this fubftance, the alkali is firft rendered cauftic by boiling it with half its weight of quick-lime, which abftracts its carbonic acid or fixed air by fuperior attraction. What is called foap-leys is a folution of the cauftic alkali in water, which is evaporated to fuch a degree of denfity as to be able to fuftain a new-laid egg. To make the finer foap, a part of this lixivium is to be diluted, and mixed with an equal quantity of olive-oil. The mixture is put on a gentle fire, and agitated, by which the union is accelerated. When the mixture begins to unite well, the reft of the lixivium is to be added to it, and the whole is to be digefted with a gentle heat, till the foap is completely made. Good foap of this kind is white and firm when cold, and is not liable to become moift on expofure to air; it is entirely mifcible with water, to which it gives a milky appearance, without exhibiting any particles of oil on the furface.

In the making of foft, liquid, green, or black foaps, cheaper oils are employed, as oil of nuts, of hemp, of fifh, &c. but tallow is the ingredient ufed in our common hard foap.

Oil may be ſeparated from ſoap by the addition of an acid, without being much altered in its properties. On this account, waters which contain any acid, either in a diſengaged ſtate, or combined with any ſubſtance except fixed alkali, decompoſe ſoap, and will not completely mix with it.

In this decompoſition, eſpecially that effected by the vitriols of lime and magneſia, which are frequently contained in water, the vitriolic acid unites with the fixed alkali of the ſoap, and forms vitriol of ſoda, or Glauber's ſalt; the lime or the magneſia combines with the oil, and forms a kind of ſoap ſcarcely at all ſoluble, which floats in a whitiſh curd like maſſes on the ſurface of the water.

The VOLATILE alkali or ammonia is ſeldom or never found in a ſimple ſtate. It is met with in nature only compounded with other bodies, in nitrous ammoniac, or in common ſal ammoniac, which is ſometimes found in the neighbourhood of volcanoes, or coal-mines which have burnt for a long time. The volatile alkali of commerce is chiefly produced from bones. This alkali is very different in its properties from the other two; its volatility is ſo great, that under the ordinary preſſure of the atmoſphere it is continually flying off in a very pungent vapour. It is ſold in the ſhops under the name of ſmelling ſalts, ſal volatile, or ſpirit of hartſhorn. The proceſs of putrefaction in animal matters, and in ſome vegetables, particularly cabbages, throws it off into the air, together with other volatile matters, which in ſome meaſure diſguiſe its ſmell. Volatile alkali is now proved to

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be a combination of two other ſubſtances, namely, the baſes of the azotic and hydrogen gaſſes. M. Berthollet has found by analyſis that 1,000 parts of volatile alkali conſiſt of about 807 parts of azote, combined with 193 of hydrogen. The volatile alkali of the ſhops, that is in its mild and concrete ſtate, when heated to a certain degree, aſſumes the form of vapour, but by a diminution of the heat returns again to the concrete form. Volatile alkali, however, deprived of the fixed air which rendered it mild, is capable of receiving a permanently elaſtic form; in which ſtate it is called alkaline air. When a mixture of alkaline air and marine acid air was made by Dr. Prieſtley over mercury, a beautiful white cloud was formed, and a diminution in the bulk of the airs took place. The cloud having ſubſided, was found to be common ſal ammoniac, or a union of the volatile alkali with the marine acid. Nitrous air admitted to alkaline air, likewiſe occaſioned a whitiſh cloud, which ſoon diſappeared, leaving only a little dimneſs on the ſides of the veſſel. Fixed air admitted to alkaline air, produced a depoſition of the common or concrete volatile alkali, in the form of oblong and ſlender cryſtals, which croſſed each other, and covered the ſides of the veſſel like a net-work. Inflammable air admitted to alkaline air, produced no particular appearance. Water abſorbed the alkaline air, and left the inflammable air as before. Azotic gas ſeemed to have no effect on alkaline air. Alkaline air is abſorbed by water, in the proportion of $\frac{7}{8}$ of

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an ounce measure of air to 1 ¼ grains of rain-water; and the water is by these means made prodigiously stronger than any of the volatile spirit of sal ammoniac or hartshorn, obtained in the common way.

CHAP.

# CHAP. III.

## ACIDS.

*Of Acids in general.—Vitriolic Acid; how obtained, &c.—Nitrous Acid; how obtained.—Muriatic Acid; how obtained, and its Use in the Arts.—Fluor Acid; dissolves Glass; employed to make Etchings on Glass.—Acid of Borax.—Phosphoric Acid.—Acid of Amber.*

ACIDS are very active substances, and when concentrated are highly corrosive. They have so general a tendency to unite with other substances, that they are never obtained pure except by art. They are generally fluid, which seems, however, chiefly to be owing to their strong attraction for water, of which few of them can be entirely deprived, and which they copiously attract from the atmosphere. One of the marks by which the presence of uncombined acids may be ascertained, is their property of changing to a red, the blue colour of infusion of violets, which alkalis change to a green. Acids are distinguished into mineral, vegetable, and animal; the subject of this book will at present confine us to those of the first class.

The acids found in the mineral kingdom are the carbonic acid or fixed air, the vitriolic, the nitrous, the muriatic, the acid of spar, the acid of borax, the acid of phosphorus, and the acid of amber.

The

The CARBONIC acid has already been treated of under the head of gaſſes.

The VITRIOLIC acid takes its name from vitriol or copperas, from which it was formerly extracted by diſtillation. In the new chemical nomenclature, it is with much more propriety called the acid of ſulphur, as it is now found to be a combination of that inflammable ſubſtance with oxygen. The pungent and ſuffocating fumes which are produced by the inflammation of ſulphur, are an acid which is imperfect from a deficiency of oxygen; and which cannot be condenſed without the aid of water. The vitriolic acid can never be entirely deprived of water, but admits of the greateſt concentration of all the acids, and may be reduced to a ſtate in which its ſpecific gravity is double that of water. The denſe and ſluggiſh appearance of the concentrated vitriolic acid has given riſe to the improper name of oil of vitriol, under which it paſſes in the ſhops.

M. Lavoiſier makes a diſtinction between this acid, as it exiſts in an imperfect and gaſſeous ſtate, and as it exiſts in the form of a tranſparent and ponderous liquid combined with water. In its former ſtate he calls it, *acide ſulphureux* (ſulphureous acid); in the latter, *acide ſulphurique* (ſulphuric acid). The ſame difference of termination is employed to expreſs the different ſtates of the nitrous acid, according as it is imperfectly or completely ſaturated with oxygen. A difference of termination is alſo given to the combinations of acids, according as they are perfectly or imperfectly ſaturated

saturated with oxygen. Thus the combinations of the sulphureous acid, are called *sulphites*; those of the sulphuric acid, *sulphats*, &c.

The vitriolic acid now used in commerce is prepared in the following manner:—A quantity of sulphur and salt-petre, grossly mixed, are placed in a vessel within a small room, lined with lead, and containing a few inches depth of water at bottom. The sulphur is lighted, and the room closed. The salt-petre serves to maintain the combustion, by the oxygenous gas which it affords; and the acid fumes which are produced are absorbed by the water. The process is repeated till the water is thought sufficiently acid. The volatile fumes are then dissipated by exposure to air, and the acid is concentrated by distilling off the superfluous water.

The vitriolic acid is said to have become concrete by cold, but it probably was not in its most perfect state. It easily parts with its oxygen to inflammable substances; if oil is mixed with it, it is converted into a dark, viscid substance, and emits sulphureous and pungent vapours.

The vitriolic acid has been thought to exist in the atmosphere, but this is a mistake. It is discovered in some waters, but in small quantity; it exists in some ores of metals, and makes one of the constituent parts of gypsum.

The NITROUS acid is a fluid of considerable weight, but does not admit of so much concentration as the vitriolic. In its most perfect form it is quite transparent and colourless, but in its ordinary state it is of an orange tawny colour, and when exposed

posed to the air it constantly emits orange-coloured fumes, which are noxious. It very readily parts with its oxygen to inflammable substances and metals; and when mixed with oil of turpentine, it explodes and flames. The oil attracts the oxygen, and burns, while the azote is suddenly set at liberty, and occasions the explosion. When nitrous acid is diluted with an equal weight of water, it is called *aqua fortis*. The nitrous acid is considerably diffused in nature. All that is sold in the shops is obtained by distilling salt-petre with the vitriolic acid.

Azotic and oxygenous gas were mixed together by Mr. Cavendish, and the electric spark was passed through them. In these trials a diminution of bulk was always observed; indeed five parts of oxygenous gas being added to three of common air, almost the whole disappeared. By continuing his experiments, he found that an acid was produced, and that acid was the nitrous.

The MURIATIC acid, in its ordinary state, is a yellowish-coloured fluid, and emits fumes which do not give the air a red tinge like the nitrous acid, but produces an appearance of mist. These fumes are noxious to the lungs, and smell like burning soot. The muriatic acid is distinguished from the vitriolic and nitrous in the strong adhesion of its component parts, which is evinced by its not parting with oxygen, and of course its having little action on inflammable substances. So strong indeed is the attraction between the principles, whatever they are, which form this acid, that they have never been separated. Its base

therefore

therefore is wholly unknown to us, and we have no other evidence than analogy to lead us to conclude that, like other acids, it contains oxygen. M. Berthollet conjectures the radical of the muriatic acid to be of a metallic nature. The muriatic acid is by far the most abundant of all the acids in the mineral kingdom; it is naturally combined with lime, magnesia, and natron, or the fossil alkali; with the latter it forms the immense beds of sal gem, and the saline matter which gives saltness to the ocean.

As the muriatic acid can only subsist in the gasseous state in the ordinary temperature and pressure of the atmosphere, it is necessary to use water in order to condense it. But the ordinary muriatic acid is capable of being combined with an additional quantity of oxygen, by being distilled with the mineral substance called manganese, or with certain preparations of lead and mercury, which readily part with oxygen. The acid resulting from this process, and which is called oxygenated muriatic acid, can only, like the former, exist in the gasseous state, and is absorbed in a much smaller quantity by water. When the impregnation of water by this gas is carried beyond a certain point, the superabundant acid precipitates to the bottom of the vessel in a concrete form. M. Berthollet has shewn that this acid gas is capable of being united with a great number of salifiable bases; the neutral salts which result from this union are capable of deflagrating with charcoal, and some of the metallic substances: these detonations are

very violent and dangerous, from the great quantity of the matter of heat which the oxygen carries along with it into the composition of the oxygenated muriatic acid.

The muriatic acid in the oxygenated state has also a remarkable power of rendering vegetable and animal matters white. The reducing of this principle to practice has, indeed, been productive of a very essential improvement in the art of bleaching, and for this too we are indebted to M. Berthollet*. By various experiments he was enabled to ascertain that the oxygenated or dephlogisticated marine acid, as it was at first called, only differs from the common marine acid, in containing a superabundance of oxygen, with which it very readily parts. He discovered further, that oxygen has a remarkable property of destroying the colours of vegetable matters; that even the dew which falls from the atmosphere, and that which comes from the nocturnal transpiration of plants, were impregnated with oxygen, sufficiently to destroy the colour of paper, slightly tinged with tincture of turnsole. The ancient prejudices concerning the dew of the month of May, a season when the transpiration of plants is most abundant, he conceives to have originated in a similar observation.

Attributing, therefore, in his own mind the common effect of whitening linen in bleach-yards to the action of oxygen, he was led to imitate that process by applying leys, and the oxygenated mu-

* Annales de Chymie.

riatic

riatic acid alternately, and by these means was enabled to make linen, &c. permanently white, by a very quick and easy process. Observing further that it was the practice in common bleaching, to make the linen, &c. in the finishing, pass through sour milk, or a very weak mixture of the vitriolic acid with water; he also tried the passing of the cloth through a very dilute solution of the vitriolic acid, and observed that it was consequently rendered of a clearer white.

The oxygenated acid may be employed either in the aerial form, or diluted with water; and the latter appears to be the most convenient mode of applying it. The effect seems to result entirely from the action of the oxygen which the acid parts with to the cloth, and which has a power of destroying vegetable colours. Perhaps the fading of dyed stuffs on being exposed to the action of the light and air may be accounted for on the same principles. The acid which M. Berthollet employed in bleaching he found had parted with all its superabundant oxygen to the cloth, and was reduced to the state of the common muriatic acid. The soap-leys seem to act in two ways; by neutralizing any of the superfluous acid which might be imbibed, it saves the cloth from being corroded; and it also prevents the suffocating fumes of the oxygenated acid from being offensive or injurious. Possibly the detergent quality of the leys may have a further effect in carrying off the colouring particles which are detached from the cloth by the action of the oxygen.

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When one or two parts of pale concentrated nitrous acid are mixed with four of fuming muriatic acid, an effervescence soon takes place, and oxygenated muriatic acid is produced; at the same time that the mixture becomes of a red colour. The mixed acid is called *aqua regia*, which has the property of dissolving gold.

The SPARRY or fluor acid was discovered by Mr. Scheele, and takes its name from the substance from which it is obtained, and which is commonly known in England under the name of Derbyshire spar. This acid when pure assumes the form of gas. In this state it is heavier than atmospheric air, extinguishes flame, and destroys animal life; it has a penetrating smell, like that of marine acid, but more powerful; and its causticity is such that it almost instantly corrodes the skin. Heat dilates it, without producing any other change. The addition of atmospherical air has the effect of producing with it a white vapour, which is more or less abundant, in proportion as the atmosphere contains more or less of humidity.

If vitriolic acid is poured on the Derbyshire spar, which is a combination of this peculiar acid with calcareous earth, and a gentle heat applied, the acid is disengaged in an aerial form. It readily combines with water, and therefore the recipient should be half filled with that fluid. The first experiments which were made of the distillation of this acid in glass vessels, were attended with a striking appearance, which required considerable acuteness for its explanation. It was observed that as soon

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as the acid gas reached the ſurface of the water, a quantity of earthy matter was depoſited. This was at firſt naturally attributed to the acid carrying over with it part of the calcareous ſtone from which it was diſtilled. Upon examination, however, it was found that the earth depoſited in the water was ſiliceous, and this gave riſe to an opinion that flint was only a compoſition of this acid with water. This hypotheſis was ſoon overturned, by obſerving that the glaſs veſſel in which the diſtillation was performed was always corroded, or in part diſſolved. In this manner it was found that the fluoric acid has the ſingular property of diſſolving glaſs. As only a moderate heat is required for the diſtillation of this acid, it is now uſual to make uſe of leaden veſſels for that purpoſe; which are not corroded by the acid. The baſe of this acid is unknown, as we are not acquainted with any ſubſtance which can abſtract its oxygen.

The fluoric acid has been ſucceſsfully employed to make etchings on glaſs, in the ſame manner as nitrous acid is applied to copper. It combines readily with earth and alkalies, but ſcarcely, if at all, acts on gold, ſilver, lead, mercury, tin, antimony, biſmuth, or cobalt, but it diſſolves their calces. It acts directly on iron and zinc, with the production of inflammable gas; and it likewiſe diſſolves copper in the metallic ſtate, though leſs eaſily than when calcined.

If BORAX is diſſolved to ſaturation in boiling water, and the vitriolic acid added in ſuch quantity as to be perceptibly in exceſs, a ſubſtance will riſe

to the ſurface of the water in the form of white ſcales, which is proved to be a peculiar acid. Many chemiſts have ſuppoſed that this acid is an artificial product, formed by a combination of the ſalts made uſe of in its manufacture. This opinion, however, has now been given up, ſince this acid has been found to exiſt in a ſtate of great purity in mineral waters, and ſince real borax may be formed by adding this ſcaly ſalt to the mineral alkali. The acid of borax requires about fifty times its weight of water for its ſolution. In a moderate heat it melts with leſs intumeſcence than borax itſelf; and the glaſſy ſubſtance, thus formed, is again ſoluble in water, having only loſt its water of cryſtallization.

The acid of borax is uſed to fuſe vitrifiable earths, with which it forms clear and almoſt colourleſs glaſſes; by the aſſiſtance of heat it diſſolves the earth precipitated from what is called the liquor of flints. It unites with ponderous earth, magneſia, lime, and alkalis, and forms with theſe ſubſtances ſaline compounds. All theſe properties, and more eſpecially its taſte, the red colour it communicates to the tinctures of violets and turnſole, and its neutral combinations with alkalies, ſufficiently indicate its acid nature; but it is the moſt feeble of all the acids, and is diſengaged from its combinations even by the carbonic acid. The acid of borax is the ſubſtance called by Homberg ſedative ſalt, from its ſuppoſed effects on the human body. It effervefces with a boiling hot alkaline ſolution, but not with metals or abſorbent earths, though it may

be united with them. It has a weak attraction for inflammable substances, particularly spirits of wine, the flame of which it tinges green. From this circumstance it has been supposed, but without sufficient proof, to contain copper.

PHOSPHORIC acid is obtained by the combustion of the bones of adult animals, which are afterwards pounded, and passed through a fine silk sieve; a quantity of dilute vitriolic acid is then poured upon the powder, but less than is sufficient for dissolving the whole. This acid unites with the calcareous earth of the bones, and forms selenite, and the phosphoric acid remains free in the liquor. The liquor is decanted off, and the residuum washed with boiling water; this water, which has been used to wash out the adhering acid, is mixed with what was before decanted off, and the whole is gradually evaporated. The dissolved selenite now crystallizes in the form of silky threads, which are removed; and by continuing the evaporation we procure the phosphoric acid, under the appearance of a white pellucid glass. When this is powdered, and mixed with one third of its weight of charcoal, we procure very pure phosphorus by sublimation. The phosphoric acid, however, as procured by the above process, is never so pure as that obtained by oxygenating pure phosphorus, either by combustion or by means of the nitrous acid.

The phosphoric acid may be rendered concrete with very little difficulty, by merely exhaling the moisture. It abounds in the animal kingdom, and is not unfrequent in the vegetable and mineral. In

this last it is found united with lead and iron, as well as with calcareous earth.

The acid of AMBER is obtained from the substance of that name, by the simple application of heat. The operation must not be carried on too far, or by too strong a fire, as the oil of the amber is apt to rise with the acid. The acid is found in a concrete form in the neck of the subliming vessel; it is soluble in twenty-four times its weight of cold water, and in a much smaller quantity of hot water. It possesses the qualities of an acid in a very small degree, and only affects the blue vegetable colour very slightly.

CHAP.

## Chap. IV.

### NEUTRAL SALTS.

*The Union of an Acid and Alkali destroys the corrosive Quality of each.—Neutral Salts do not communicate the saline Quality to other Bodies.—Crystalline Form—how decomposed.*

NATURAL productions pass by gradations into each other; and I might have given an account of the primitive earths immediately after that of the alkalies, as these substances have several properties in common, particularly that of uniting with acids, and forming neutral compounds. Metals also are capable of being united with acids, and of forming with them saline substances. A lucid order will however be better preserved, by at present confining our attention to the consideration of such neutral bodies as are formed by the union of an acid and an alkali.

To a person unacquainted with chemistry, it is a striking circumstance that two acrid and corrosive substances should by their union form a compound very mild and inactive. Such however is the case, and what is still more remarkable, their previous acrimony, and tendency to combine, renders the neutral body proportionably more inoffensive. Thus an alkali united with vitriolic acid, may be received into the body with much less caution than when combined with the aerial or carbonic acid. The

neutral salts in general have not so strong a taste as the simple, their tendency to combination and their solubility being less considerable; but the criterion which more especially distinguishes them from the former is, that they cannot, like the simple salts, communicate the saline properties to other bodies. Their crystalline form is likewise a circumstance which very generally distinguishes the neutral from the simple salts. The volatility of the neutral salts is not in general so great as that of the simple salts.

Neutral salts may in many cases be decomposed by heat alone, but in general it is necessary to have recourse to elective attraction, or the addition of a third substance. When the decomposition is effected by heat alone, the more volatile part is forced off: but it seldom succeeds in this way, the ingredients adhering so strongly that they rise together. It then becomes necessary to have recourse to elective attraction. Thus, if from a neutral salt we wish to obtain the acid pure, we apply another acid which has a greater attraction for the alkali. If our object is to obtain the alkali separate, we apply a substance which has a stronger attraction for the acid.

# Chap. V.

## VITRIOLIC SALTS.

*Glauber's Salt; how decomposed; Solution of it left to cool crystallizes on being shaken.—Vitriolated Tartar.—Vitriolated Ammoniac.*

THE first substances of this kind which challenge our attention, are Glauber's salt and vitriolated tartar, or as they are denominated in the new chemical nomenclature, sulphat of soda, and sulphat of pot ash. The former of these neutral salts is composed of the vitriolic acid, combined with the mineral alkali; and the latter of the same acid with the vegetable alkali. They both have a saline bitterness. By heat their ingredients may be raised into vapour, but no one simple salt will separate them, as no acid has a stronger attraction for the alkali than the vitriolic, nor any alkali a stronger attraction for the vitriolic acid than the fixed Dr. Stahl proposed the effecting of this separation as a problem. He knew how to solve it, and it was afterwards done by a double elective attraction. Another more curious method is this: take Glauber's salt or vitriolated tartar, melt the salt in a hot crucible, and add to it first a quantity of charcoal, which has a stronger attraction for the oxygen of the vitriolic acid than the latter has for the alkali. These being exposed to heat, the

the charcoal in part disappears, and the mixture acquires a deep red colour. If the matter is poured out, we find it to be an *hepar sulphuris*, or liver of sulphur, the charcoal having carried off with it the oxygen in the form of carbonic acid gas.

Glauber's salt is more fusible than vitriolated tartar, melting in a moderate degree of red heat. The solution of Glauber's salt forms into columnary crystals, which have generally six sides, four principal, and two which seem accidental. Its crystals, containing a large quantity of water, are liable to have it abstracted from them by the atmosphere, when they fall to powder, or in chemical language *effloresce*. How much water Glauber's salt is capable of containing, is known by its requiring twice its weight of water to crystallize. The water should be added in a boiling state, and the mixture boiled a little afterwards; it may be set by in a quiet place, and will be found crystallized the next day, or will suddenly assume that state on being shaken. On crystallizing, a quantity of heat is perceived to be emitted by the substance passing from a fluid to a solid state, and consequently losing some of its latent heat.

Of Glauber's salt, all that is used at present is produced by art. It is said to be produced by nature in the waters of mineral springs, and of the sea. But the salt found in them is usually not Glauber's salt but Epsom salt, consisting of the vitriolic acid and magnesia. Glauber's salt is obtained by uniting the vitriolic acid with the mineral

alkali

alkali of common salt, as happens in the process for obtaining the muriatic acid.

VITRIOLATED TARTAR is distinguished from Glauber's salt, by a less degree of fusibility. It requires for its fusion the strongest fire. Its crystals are harder, but less bright, and do not contain so much water as those of Glauber's salt. Hence they are not liable either to spontaneous efflorescence, nor to watry fusion, but, like other salts, which contain little water, attract it strongly. This salt decrepitates * in the fire. Vitriolated tartar does not appear to be a fossil salt; it is found in the juices of vegetables, and remains in their ashes after they are burnt. What is used in dying and medicine, is obtained by art, most commonly by adding vitriolic acid to nitre, in order to dislodge the nitrous acid.

One hundred parts of vitriolated tartar contain, according to Bergman, about 52 parts of fixed vegetable alkali, 40 of vitriolic acid, and 8 of water of crystallization.

The vitriolic acid combined with the volatile alkali is called AMMONIACAL VITRIOL, or sulphat of ammonia. Ammoniacal salts, it is proper to remark, are so called from *ammon*, an Arabic word for sand; or, as Pliny conjectures, from the temple of Jupiter Ammon, near which ammonia used to be found in great quantities, on account of the ca-

* In decrepitation the crystals burst, and fall into powder, from the expansion of the water which they contain, by the heat. This occasions that crackling noise which common salt makes when thrown into the fire.

mels dung and urine brought thither. With reſpect to the general properties of ammoniacal ſalts, as their alkali is very volatile, they are unable to bear any great degree of heat without being converted into vapour, though much more than might be expected from their ingredients. They emit pungent fumes if a fixed alkali or lime is added to them, as theſe ſubſtances, having a ſtronger affinity with the acids, expel the volatile alkali.

When ammoniacal vitriol is very pure, it has the form of needles, which, on careful examination, are found to be flattened priſms of ſix ſides, two of which are very broad, terminated by ſix-ſided priſms irregularly formed; but the whole figure of the cryſtallization is ſubject to conſiderable varieties. This ſalt is ſometimes in the form of quadrangular priſms, and is ſometimes obtained in very thin plates.

Its taſte is bitter and urinous; it is light, and very friable. It is ſcarcely changed by expoſure to air; it does not effloreſce like Glauber's ſalt, but on the contrary ſlightly attracts the humidity of the air. It is very ſoluble in water, two parts of cold or one of hot water being ſufficient to hold it in ſolution; it cryſtallizes by cooling; but the moſt perfect cryſtals are obtained by ſpontaneous evaporation. It likewiſe unites with ice, which it melts, producing at the ſame time an exceſſive degree of cold. It does not act on the earths, nor on magneſia; though this laſt, according to Bergman, ſeems to decompoſe it after a length of time.

If

If mild fixed vegetable alkali, that is alkali combined with the carbonic acid gas, is diſtilled with ammoniacal vitriol, a double decompoſition and combination take place. The vitriolic acid unites with the fixed vegetable alkali, and forms vitriolated tartar. The carbonic acid gas being at the ſame time volatilized, together with the volatile alkali, alſo in a ſtate of gas, both unite, and form an ammoniacal ſalt, which cryſtallizes in the recipient.

Ammoniacal vitriol ſeems not to exiſt in a ſtate of nature; nor is it uſed either in medicine or the arts.

## CHAP. VI.

### NITROUS SALTS.

*Common Nitre; Phenomena attending its Deflagration with inflammable Substances.—Natural History of Nitre.—Cubic Nitre.—Union of nitrous Acid with various Earths.—Nitrous Ammoniac.*

COMMON NITRE, or nitrat of pot-ash *, consists of the vegetable alkali and nitrous acid. Nitre was unknown to the ancients; the substance which they distinguished by that name was a fossil alkali, for we are told by Pliny that it was detergent, and used in making glass. It is uncertain when nitre was discovered, but we find it mentioned in the earliest chemical writers. Nitre melts in a very gentle heat, and in a greater degree of heat totally evaporates. Cold water dissolves one-sixth of its weight; and hot water about its own weight of this salt. Its crystals are more regular than those of any other salt (being prisms of six sides) having very little water in their composition, and therefore not liable to spontaneous evaporation. Its most extraordinary property is its deflagration with inflammable substances, which happens from the decomposition of its acid, by which a large quantity of oxygenous gas is set at liberty. To the production of this air is owing the rapid combus-

* Commonly known under the name of salt-petre.

tion

tion of mixtures of nitre and inflammable substances, as evinced in * gunpowder. When nitre is melted by itself, no particular effect takes place; but if charcoal is added to it in its melted state, deflagration or detonation takes place. We are therefore not to consider nitre itself as an inflammable substance, but only as affording the pabulum of fire. If we continue to add charcoal, we find that the effect becomes less and less, till it entirely ceases. What remains in the crucible is different from nitre, it requires more heat to keep it fluid, and upon examining it we find it a pure vegetable fixed alkali. The charcoal disappears, because it is converted into carbonic acid gas by being united with oxygen; and the other component part of nitrous acid, the azote, by being deprived of its oxygen, is also volatilized and dispersed.

When the deflagration is performed with sulphur instead of charcoal, the consequences are considerably different. Like charcoal indeed, when sulphur is added in a certain quantity, it will produce no further deflagration; but when sulphur is used, the flame is insupportable to the eye, and the appearance of inflammation is greater though the noise is less. If the residuum is dissolved in water, it will readily crystallize, and is found to be vitriolated tartar. The reason that less explosion is produced by sulphur than charcoal is, that the former, when united with the oxygen of the nitre, becomes fixed; whereas charcoal united with the same principle

* The reader will do well to consult what has been said respecting gunpowder in Book II.

is

is converted into gas, and escapes with violence. The formation of vitriolated tartar is owing to the production of vitriolic acid from the sulphur and the oxygen, which combines with the fixed vegetable alkali.

The detonation of nitre is a nice test of the inflammability of bodies, as there are many which are found to have this property when added to nitre in a state of fusion, which exhibit no signs of it on ordinary occasions.

Nitre exists in large quantities in nature, and is continually formed in inhabited places; it is found in great quantities upon walls which are sheltered from the rain; and the Bishop of Llandaff collected a considerable portion from the decayed mortar of an old barn.

There appear to be three principal circumstances that promote its formation; the first is, the presence of chalk, or any other calcareous earth, as appears by its being collected from walls covered with plaster, or from the ruins of ancient edifices. This salt is likewise found perfectly pure in chalky earths. The Duc de la Rochefoucault obtained it, in the proportion of one ounce in the pound, from the chalk of Roche Guyon.

The second circumstance necessary for the production of this salt, is the putrefaction, or spontaneous decomposition of vegetable and animal matters. It is a well known fact, that places which are moistened with animal liquids, or contain animal matters in a state of putrefaction, such as dunghills, stables, privies, &c. produce much nitre. This

constant

constant observation has been applied to the formation of artificial nitre-beds. Dry ditches are dug and covered with sheds open at the sides; these are filled with animal substances, such as dung, the excrements of quadrupeds, or birds, with the remains of vegetables. These matters are from time to time watered, especially with water charged with animal or vegetable matters capable of putrefaction, and they are turned up to renew their surfaces from time to time. When the putrefaction is in an advanced stage, a small portion of the matter is taken up and lixiviated, to ascertain whether it contains nitre; and when it is found sufficiently charged with that salt, the whole is lixiviated.

The third circumstance, which, in the opinion of some, is supposed to favour the production of nitre, is the access of air; this is the cause of the formation of the nitre found on walls; and for this reason it is that nitre-beds require to be frequently turned over, in order that the air may touch them in all points. The necessity of the access of air is said to be still more evidently shewn by the nitre contained in chalk, as it is never found below a certain depth. When the three circumstances here treated of are united, the production of salt-petre is very abundant. Nitre-beds ought always to be constructed on these principles.

The theory of the formation of nitre has not been long known. Glauber, and many other chemists since his time, supposed nitre to exist ready formed in vegetables, from which they imagined it to pass into animal substances, and to become disengaged by putrefaction; but it was soon perceived,

that vegetables do not contain a sufficient quantity of nitre to account for what is obtained from nitre-beds. M. Thouvenel, whose dissertation on the formation of nitre was honoured with the prize of the academy, has made many experiments to discover its origin: he found, that the nitrous acid is formed by the combination of an elastic fluid, disengaged from animal matters in a state of putrefaction, and pure air. He has likewise discovered, that the nitrous acid, once formed, combines with calcareous earth, when any animal matters are made use of; and that the remains of vegetables are useful to afford the fixed alkali, which is the base of common nitre. But M. Thouvenel did not determine the nature of the gas, which is disengaged from putrefying animal matters. It is to Mr. Cavendish that we are indebted for the proof that it is the same gas, which constitutes one of the principles of the atmosphere, under the name of azote, or phlogisticated air, or atmospheric mephitis. His experiment, wherein the nitrous acid was formed by the combination of this gas with vital air, by means of the electric spark, has been already mentioned.

Cubic Nitre, or nitrat of soda, consists of the nitrous acid and the fixed mineral alkali. It resembles common nitre in all its striking qualities; almost its only difference is the form of its crystals, which is a paralellopiped. The crystals adhere so strongly, that they are scarcely ever found distinct and regular. For the deflagration of cubic nitre, charcoal is most proper; when performed with sulphur, Glauber's salt is produced.

Cubic

Cubic nitre has not yet been found in nature, but is always produced by art. The ſhorteſt method is adding nitrous acid to foſſil alkali. Its taſte is cooling, and rather more bitter than that of common nitre. Fire decompoſes it, but it decrepitates, and does not ſo eaſily melt as common nitre; like that ſalt, however, it gives out vital air during its decompoſition. It is ſlightly deliqueſcent when expoſed to air. It is more ſoluble in cold water than the common nitre, two parts of water, at the temperature of ſixty degrees, diſſolving one of the ſalt. It is ſcarcely more ſoluble in boiling water, and therefore cannot be had in regular cryſtals, except by ſlow evaporation.

Siliceous earth combines with the baſe of this ſalt, and diſengages the nitrous acid; clay likewiſe ſeparates the acid, and affords a reſidue in the form of frit, which is porous and opake when a ſtrong heat has been applied. Ponderous earth decompoſes this ſalt, and diſengages the mineral alkali. Magneſia and lime do not ſenſibly change it. The vegetable fixed alkali has a ſtronger affinity with its acid than the mineral. This fact is very eaſily ſhewn. If a heated ſolution of cubic nitre is divided into two parts, and the cauſtic vegetable fixed alkali added to one of them, it will afford priſmatic cryſtals during its cooling; no cryſtals, however, will be obſerved in the other part, becauſe cubic nitre does not cryſtallize by mere cooling without evaporation.

The neutral ſalts hitherto examined produce no effect whatever on cubic nitre; if theſe ſalts are

diſſolved together in the ſame water, they cryſtallize ſeparately, and each in its ordinary manner; the nitre and Glauber's ſalt by cooling; the vitriolated tartar and cubic nitre by evaporation. All theſe properties ſhew, that cubic nitre differs from common nitre.

Nitrous Ammoniac, or nitrat of ammoniac, is compoſed of the nitrous acid and volatile alkali. It is more ſoluble and more fuſible than the vitriolic ammoniac. When the heat is increaſed a little above what is neceſſary for its fluidity, it is converted into copious vapours. The degree of heat neceſſary for its fuſion is a little above that of boiling water; and if more heat is ſuddenly employed, it has the ſingular property of undergoing deflagration, though no inflammable ſubſtance ſhould be added to it, and even in a cloſe veſſel. This ſeems to depend on the decompoſition of the volatile alkali.

M. Berthollet having expoſed ammoniacal nitre to the action of heat in a pneumato-chemical and diſtilling apparatus, and having obſerved the phenomena of this operation more carefully than had been done before, remarks, that it is not a true detonation which takes place, but a ſudden and inſtantaneous decompoſition, in which part of the volatile alkali is entirely deſtroyed. The water obtained in the receiver contains a ſmall part of the nitrous acid diſengaged in proportion to the quantity of volatile alkali decompoſed; and the latter gives out phlogiſticated air or azotic gas. The liquid product of this operation being weighed, a greater quantity of water is found than

exiſted

exiſted in the ammoniacal nitre; and M. Berthollet thinks that this ſuperabundant water is formed by the union of the inflammable gas, which is one of the principles of the volatile alkali, with the vital air of the nitrous acid. The azotic gas, or other principle of the volatile alkali, which is ſix times more in quantity than the inflammable gas, is diſengaged and collected under the veſſels of the pneumatic apparatus.

This ſalt diſſolves readily in water, and in a very large quantity, but it has not ſo ſtrong an attraction for water as to be deliqueſcent. It may be decompoſed by the vitriolic acid, or either of the fixed alkalis. The nitrous ammoniac is contained in the juices of ſome plants, but it is uſually prepared by artificial combination.

## Chap. VII.

### MURIATIC SALTS.

*Sal Digestivus.—Common Salt.—Rock Salt.—Natural History of Salt.—Saltness of the Ocean.—Uses of common Salt in the Arts.—Sal Ammoniac.—Natural History of Sal Ammoniac.*

THE combinations of the muriatic acid with the alkalis are, 1st, Sal Digestivus, or muriat of pot-ash, which has also been called the febrifuge salt of Sylvius, and is a composition of the muriatic acid with the fixed vegetable alkali. Its taste is penetrating and bitter; its crystals cubical, but almost always confused and irregular. In the fire it decrepitates, that is, its crystals suddenly break and fly in pieces by the rarefaction of the water which enters into their composition. If the heat is then continued, and sufficiently strong, it melts, and is volatilized without decomposition. It is not much altered by exposure to the air; it is however slightly deliquescent. About three parts of cold water are required to hold one part of this salt in solution, and hot water does not dissolve a greater quantity.

Clay appears to decompose this salt in part, for marine acid is obtained by distilling it with the clays found in the vicinity of Paris. This operation, however, in fact affords only a small quantity of acid, and sand seems to have a similar effect. Ponderous

derous earth ſeizes its acid, and ſeparates the alkali, according to Bergman. Magneſia and lime do not at all change it. The vitriolic and nitrous acids diſengage the muriatic acid with effervefcence. This ſalt is found in a ſtate of nature, but never in conſiderable quantities; it is found in ſea-water, and in the water of ſalt ſprings, and it exiſts, though rarely, in places where nitre is found; it is likewiſe met with in the aſhes of vegetables, and in animal fluids. It is not employed in the arts, and its bitter taſte prevents its being uſed for culinary purpoſes. In moſt of its properties, however, it is very ſimilar to common ſalt.

2d. Common or Marine Salt is compoſed of the muriatic acid and the mineral fixed alkali, and is therefore the *muriat* of *ſoda* of the new nomenclature. This ſalt requires a full red heat for its fuſion; ſoon after this it begins to evaporate in white fumes. It has a ſtrong attraction for water, ſo as to deliqueſce in a moiſt air. During evaporation, the cryſtals of this ſalt form at the top of the ſolution, contrary to thoſe of other ſalts, which form at the bottom. When the evaporation is carried on quickly, it forms into thin irregular cruſts, and this is the ſtate in which we commonly have it. When the evaporation is ſlow, it aſſumes the cubic form, and the ſmalleſt cryſtals are the moſt regular; but if examined accurately, one of their ſides will be found a little hollow. The larger cryſtals have a pyramidal hollow apex, with a broad baſe. This is owing to their ſuperior ſurfaces being dry when floating in the water, while

their inferior surfaces are moistened. Hence, as all dry bodies have a repulsion for water, and as their inferior surfaces have a tendency to sink, they are hollowed into little pits on the superior surfaces.

This salt contains little water of crystallization, and decrepitates in the fire. If frequently dissolved, evaporated, and dried, its quantity is more diminished than that of any other salt. By decomposition we obtain either its acid or its alkali. The old chemists used to obtain its acid by heat alone, but this is troublesome, and requires vessels capable of enduring great heat. It is most readily decomposed by the vitriolic acid, which has the strongest attraction for the alkali. The nitrous acid will also decompose it, but is more liable than the vitriolic acid to come over with the muriatic. Some water must be put into the retort with the vitriolic acid, otherwise the muriatic acid will come over in fumes so copiously as to burst the vessels. The quantity of the water should be about half that of the vitriolic acid; one half of which should be put into the receiver to condense the fumes of the muriatic acid, and the other half mixed with the vitriolic to prevent its too sudden action. Glauber's salt remains after this operation, and this is the usual way of preparing it. The way to decompose marine salt, so as to obtain its alkali, is, first to expel the muriatic acid by means of the nitrous; we thus obtain cubic nitre, which must be deflagrated to obtain the alkali. A better method, however, is to mix a solution of marine salt with caustic vegetable alkali; by evaporation muriat of pot-ash

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is obtained, and the remaining water contains the mineral alkali, pure and disengaged.

Common salt is the most useful of saline bodies; for though there are some which resist putrefaction equally well, there is none which is so friendly and agreeable to the human stomach. Its agreeable qualities are not indeed confined to man; most other animals indicate a great fondness for it. The rock salt, or sal gem, though only one form of common salt, does not melt so easily as the common crystals. The most remarkable mine of this salt is at Cracow, in Poland, where there is thought to be sufficient to supply the whole world many thousand years. In this mine there are houses, chapels, and streets of rock salt, which, when illuminated, afford a beautiful prospect. This salt is also obtained from some springs. When found in the earth it is seldom crystallized in any regular form; it has various degrees of whiteness, and is often found coloured; in this latter state it is more particularly called sal gem, because it often has the appearance and transparency of gems.

The ocean differs in saltness in different climates. It is salter towards the equator than near the poles. This seems to arise from the different quantities of water which are evaporated, in proportion to those which fall in rain. One pound of sea water in the Baltic yields about a quarter of an ounce of salt; near Holland half an ounce; and in the British seas about two ounces. Boyle has also observed, that in places of great depth the water is saltest at the bottom.

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In the voyage made towards the north pole in 1773, it was found, that the ſea-water at the Nore contained not quite one thirty-ſixth of ſalt; at the back of Yarmouth ſands, not quite one thirty-ſecond; off Flamborough Head, rather more than one twenty-ninth; off Scotland, rather leſs than one twenty-ninth; latitude 74°, at ſea, one twenty-ninth; latitude 78°, rather leſs than one twenty-eighth; latitude 80°, near the ice, not quite one thirtieth; latitude 80½°, under the ice, not quite one twenty-eighth; latitude 68°. 46, rather more than one twenty-eighth; latitude 65, at ſea, rather leſs than one twenty-eighth. Dr. Hales got only one twenty-ſeventh from water taken up in the Mediterranean, and one twenty-ninth from water taken up at the Nore. Dr. Rutty ſays, he procured one twenty-fifth from water taken up in latitude 65; one twenty-eighth from water taken up near Dublin; and one thirtieth from water taken up at Dungarvan; and Dr. Lucas, that he obtained one twenty-fifth from water taken up near Harwich. From other obſervations alſo it has appeared, that water from near Teneriff contained about one thirty-ſecond of ſalt, and that ſome from Saint Jago contained fully one-fourth. Further experiments are needed to aſcertain the ſaltneſs of the ſea in different latitudes with preciſion.

The ſalt commonly uſed for culinary purpoſes, and known by the name of bay-ſalt, is obtained from the water of the ſea by evaporation. This evaporation is in ſome places performed by the heat of the ſun, the water being let into ſhallow trenches, in order to expoſe as large a ſurface as

 poſſible.

possible. This method is practised in the southern provinces of France, and on a very large scale near Aveiro in Portugal. In the northern provinces, where the heat of the sun is not sufficiently great, artificial fires are employed. In some salt-works these two methods are united; and in England, and countries where salt rock is plentiful, that substance is dissolved in salt water, and then evaporated *. In very cold countries another method is

* 'A great quantity of rock salt is used at Northwich, in order to strengthen their brine springs, and a much greater quantity is sent coastwise to Liverpool, and other places, where it is used either for strengthening brine springs or sea water; much of this rock salt was formerly exported to Holland, and it is still sent to Ireland for the same purpose. Rock salt, and the white salt which is at Northwich, chiefly made from rock salt, is exported free from the salt duty; and I was informed, that the quantity, which is annually exported from Northwich, is so great, that if it paid the duty, it would bring in to government, a sum not much short of four hundred thousand pounds a year. "According to the best accounts I have been able to procure, the gross duty on salt made in South Britain, amounts annually to seven hundred thousand pounds(*a*)." The duty on salt made at Northwich is about seventy thousand pounds a year, or a tenth part of the whole duty(*b*).

'The Northwich rock salt is never used at our tables in its crude state; and its application to the pickling or curing of flesh or fish, or preserving any provisions, without its being previously refined into white salt, that is, without its being dissolved in water, and boiled down into what is called white salt, is prohibited under a penalty of 40 *s.* for every

(*a*) Camp. Sur. of Brit. Vol. II. p. 26.

(*b*) Since I received this information, an additional duty of 10 *d.* a bushel has been laid, in 1780, on salt. The whole duty now amounts to 4 *s.* 2 *d.* a bushel, the bushel weighing 56 lb. The makers of salt can afford, in most places, to sell their salt, exclusive of duty, from 8 *d.* to 10 *d.* a bushel.

pound

is employed to ſeparate the ſalt from ſea-water. The water is expoſed in trenches on the ſea-ſhore, where

pound of rock ſalt ſo applied. The pure tranſparent maſſes, however, of rock ſalt, might, probably, be uſed by us with our food, without any ſort of danger or inconvenience; at leaſt, we know that rock ſalt is ſo uſed, without being refined, both in Poland and in Spain. In the laſt of theſe countries, at Cordova in the province of Catalonia, there is a ſolid mountain of rock ſalt, between four and five hundred feet in height, and a league in circuit; its depth below the ſurface of the earth is not known (*c*). This prodigious mountain of ſalt, which has no mixture of other matter with it, is eſteemed ſo ſingular an appearance, that it is thought to militate very much againſt the opinion of thoſe, who would derive the origin of all the beds of rock ſalt, which are found under the ſurface of the earth, from the evaporation of ſalt water, left in ſubterraneous caverns, either at the deluge, or upon ſome more local commotions of the globe.

'The quantity of rock ſalt which may be diſſolved in a definite quantity, ſuppoſe a pint or 16 avoirdupoiſe ounces of water, is differently eſtimated by different authors. Boerhaave is of opinion that 16 ounces of water will not diſſolve quite 5 ounces of rock ſalt (*d*); Spielmann thinks that they will diſſolve $6\frac{1}{2}$ ounces (*e*); Newmann agrees with Spielmann (*f*); Eller ſays, that 7 ounces of foſſile ſalt may be diſſolved in 16 ounces of water (*g*); laſtly, Hoffmann aſſures us, that 16 ounces of water will not diſſolve above 6 ounces of common ſalt (*h*). I have

(*c*) Hiſt. Nat. de l' Eſpag. p. 406.—See an account of ſimilar mountains of rock ſalt, in Shaw's Travels, p. 229, and in Pliny's Hiſt. Nat. l. xxxi. c. 7.

(*d*) Chem. vol. I. p. 476.

(*e*) Inſt. Chem. p. 48.

(*f*) Newmann's Chem. by Lewis, p. 256.

(*g*) Obſ. Phy. Chem. L. ii. Ob. xvi.

(*h*) Ber. Mem. 1750.

where it forms so thin a stratum, that the cold of the atmosphere acts powerfully in congealing it. As the

have tried this matter with distilled and with common water, and in various degrees of heat, and cannot but be of opinion, that Hoffmann's experiment approaches nearest to the truth; I never could dissolve *quite* 6 ounces of rock salt in 16 ounces of water. It is not wholly improbable, that different sorts of rock salt may differ somewhat with respect to their solubility in water.

If it be admitted, that 16 ounces of water can dissolve 6 ounces of salt and no more, then we may be certain, that no brine spring, in any part of the world, can yield 6 ounces of salt from a pint of the brine. For brine springs are, ordinarily, nothing but water in which fossile salt has been dissolved; but a pint of the strongest brine cannot contain so much salt as is contained in a pint of water, which has been saturated with 6 ounces of salt; for a pint of water, in which 6 ounces of salt have been dissolved, is increased a little in bulk, it will do more than fill a pint measure, and the salt left in the surplus will shew, how much the salt, contained in a pint of the strongest brine, falls short of 6 ounces. Or, we may consider the matter in the following manner, which will, perhaps, be more intelligible; 16 ounces of water, impregnated with 6 ounces of salt, constitute a saturated brine, weighing 22 ounces; if therefore we would know how much salt is contained in 16 ounces of such brine, by the rule of proportion we may argue, that if 22 ounces of brine contain 6 ounces of salt, 16 ounces of brine will contain $4\frac{4}{11}$ ounces of salt. Hence we may infer, that the strongest brine springs will not yield much above one quarter of their weight of salt (*i*).

Dr.

(*i*) ——— Several pits at Northwich, and at Barton in Lancashire, contain no less than six ounces of salt upon sixteen of brine, which is as large a proportion of salt as water will dissolve. *Newm. Chem.* p. 212, Lewis's note. — The author

the frozen part consists of mere water, the fluid which remains is consequently more concentrated.

The

'Dr. Leigh, who first shewed the manner of refining rock salt, informs us, that some of the strongest springs at Northwich, gave seven or eight ounces of salt from a quart of brine; but a quart of brine weighs considerably more than 32 ounces, the weight of a quart of water; so that the Northwich springs, from this account, do not yield a quarter of their weight. At Middlewich there is said to be one salt spring, which is stronger than the rest, this spring yields a *full fourth* part of salt (*k*), and hence it is, probably, fully saturated. We have an account in Kircher's works, of some famous brine springs in Burgundy, from which we learn, that one hundred pounds weight of the strongest brine, gave twenty-five pounds, or just *one fourth* of its weight of white salt (*l*).

'There are a great many brine springs in Cheshire, Worcestershire, Staffordshire, Hampshire, and in other parts of Great Britain, some of which are sufficiently rich in salt to be wrought with profit, others not. From what has been before advanced, the reader will readily comprehend that sixteen tons of the strongest brine consist of twelve tons of water, and of four tons of salt; and that, in order to obtain these four tons of salt, the twelve tons of water must be, by some means or other, evaporated, so as to leave the salt in a concrete form. Suppose there should be a brine, which in sixteen tons should contain fifteen tons of water, and only one ton of salt; yet it may chance, that such a weak brine may be wrought with more profit than the strongest; for the profit arising from the boiling of brine into salt, depends as

much

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author here is fallen, probably, into a little mistake, by confounding a pound of water with a pound of brine; for if a pound or 16 ounces of water will only dissolve 6 ounces of salt, a pound of the brine, thus formed, will only hold 4 4/11 ounces of salt.

(*k*) Philos. Trans. N° 53.

(*l*) Kerch. Mun. Sub. Tom. II. Cap. XI.

The operation is then completed by means of artificial heat.

Pure clay has very little action on marine salt. Ponderous earth decomposes it, but lime and magnesia produce no effect. Common salt is used to vitrify the surface of some kinds of pottery. This is done by throwing a certain quantity of it into the furnace, where it is volatilized, and applies itself to the surface of the pottery. This is the kind of glazing used in the making of white English pottery. Common salt is also used in making glass, to render the glass whiter and clearer. It is also employed as a flux to facilitate the precipitation of

much upon the price of the fuel used in boiling it, as upon the quantity of salt which it yields. Thus the sea water, which surrounds the coasts of Great Britain, is said to hold seldom more than one thirtieth, or less than one fiftieth part of common salt; but fuel is so cheap at Newcastle, that they can evaporate thirty or forty tons of water, in order to obtain one ton of salt, and yet gain as much clear profit as those do, who, in counties less favourably situated for fuel, boil down the strongest brine.

'The advantage resulting from strengthening weak brine or sea water, by means of rock salt, is very obvious. Suppose that the sea water at Liverpool, where large quantities of rock salt are refined, would yield one ton of salt from forty-eight tons of water, then must a quantity of fuel sufficient to evaporate forty-seven tons of water be used in order to obtain one ton of salt. But if as much rock salt be put into the forty-eight tons of sea water, as can be dissolved in it, then will the sea water resemble a brine fully saturated, each sixteen tons of which will give four tons of salt, and the whole quantity yielded by the evaporation of forty-seven tons of water, will be twelve tons of salt.'

*Watson's Chem. Ess.* vol. II. p. 42.

metals

metals from the ſcoriæ, and to prevent their calcination from the contact of the atmoſphere.

3d. Common SAL AMMONIAC is the muriat of ammoniac of the French chemiſts, and conſiſts of the muriatic acid united to the volatile alkali. This ſalt is converted into vapour before it melts, but may be brought into fuſion by being combined with other ſubſtances, or even uncombined, if properly confined. When thrown into the fire, it increaſes the flame, and tinges it with a blue colour, eſpecially the flame of charcoal. When the air is very moiſt, this ſalt deliqueſces. It is very remarkable for producing a great degree of cold when mixed with water.

If we wiſh to obtain the acid of ſal ammoniac, we may expel it by means of the vitriolic acid, but the fumes cannot be condenſed without great difficulty. For obtaining its alkali, the chemiſts generally employ the vegetable, as it is the cheapeſt. The quantity of vegetable alkali uſed is generally equal, but perhaps ought a little to exceed, that of the ſal ammoniac; the water is in general equal in weight to the alkali, and a volatile alkali ſufficiently ſtrong is obtained. The product is different, according to the mildneſs or cauſticity of the fixed alkali. When a mild fixed alkali is uſed, ſo much volatile alkali riſes, that Du Hamel and others thought part of the fixed alkali was volatilized, and roſe along with it. This however is found to be owing to the carbonic acid, which made part of the weight of the fixed alkali, being transferred to the volatile alkali.

The

The ſal ammoniac of commerce is in the form of cakes. It is prepared at Cairo from the ſoot of camels dung, which is burned there inſtead of wood. This ſoot is put into round bottles a foot and a half in diameter, terminated by a neck two inches high; each bottle contains about forty pounds of this ſoot, and affords nearly ſix pounds of the ſalt. Theſe veſſels are expoſed to the heat of a furnace which acts on their bottom, while the upper part, being cooler, ſuffers the ſalt to be condenſed there. When the operation, which occupies three days, is finiſhed, the bottles are broken and the ſalt taken out; it receives the form of the upper part of the ſubliming veſſel, and the cakes are therefore convex and unequal, with a protuberance on one ſide from the neck of the ſubliming veſſel.

Pomet has deſcribed a kind of ſal ammoniac in loaves, ſimilar to thoſe of ſugar with the point cut off, and which are imported into France by the way of Holland. This kind is made in the Eaſt Indies. ' Sal ammoniac is, however, now made in large quantities in Britain. The volatile alkali is obtained in an impure liquid ſtate from ſoot, or bones, or any other ſubſtance which affords it; to this the vitriolic acid is added, and the vitriolic ammoniac thus produced is decompoſed by common ſalt, by a double affinity, or elective attraction; the vitriolic acid combining with the mineral alkali, and the marine acid with the volatile alkali. The liquor therefore contains Glauber's ſalt and ſal ammoniac, which are ſeparated by cryſtallization; and the ſal ammo-

niac is ſublimed into cakes for ſale. Lord Dundonald extracts volatile alkali from pit-coal; but whether it can be afforded cheaper for the general purpoſes of commerce, than that of the above proceſs, is not, I believe, yet aſcertained.* '

The taſte of ſal ammoniac is penetrating, acrid, and urinous. The form of its cryſtals is a hexahedral pyramid. Cubical cryſtals are ſometimes, though rarely, formed in the middle of the concave and hollow parts of the loaves which are produced by ſublimation.

This ſalt poſſeſſes a ſingular property, namely, a kind of ductility, ſo that it rebounds under the hammer, and may be bended; a circumſtance which renders it difficult to pulveriſe it.

Sal ammoniac is not decompoſed by clay, and by magneſia very imperfectly. Lime, and likewiſe ponderous earth, ſeparate the volatile alkali, even without the aſſiſtance of heat. If ſal ammoniac is triturated with quick-lime, the ſtrong ſmell of alkaline gas is immediately perceived.

* Fourcroy's Chemiſtry. Note of the Tranſlator.

CHAP.

## CHAP. VIII.

### COMBINATIONS OF THE OTHER MINERAL ACIDS.

*Sparry Tartar.—Sparry Soda.—Borax; its Properties; its Use in the Arts.—Combinations of Salts with Metals.*

THE combinations of the other mineral acids with the alkalies, have in general been very imperfectly examined, and I ſhall therefore be very brief in treating of them.

The SPARRY TARTAR, or fluat of pot-aſh of the French chemiſts, is compoſed of the acid of ſpar united to the vegetable alkali. It is always in a gelatinous form, and has ſo ſtrong an attraction for water, that it cannot be cryſtallized. According to Scheele, it is acrid, cauſtic, and deliqueſcent, when dried and melted; he compares it in this ſtate to the liquor of flints. It appears, that the fire diſengages the ſparry acid, and that the ſiliceous earth taken up by the acid melts into a ſoluble earth by means of the fixed alkali. This ſalt has not been applied to any uſe. Of the ſparry ſoda ſtill leſs is known; and the ſame may be affirmed of the ſparry ammoniac.

The combinations of the acid of borax have not attracted much more attention, except the ſubſtance from which this acid derives its name. BORAX, the borat of ſoda of M. Lavoiſier, is compoſed of a peculiar acid united to the mineral alkali. The

form in which it is expoſed to ſale is that of cryſtals, very tranſparent, and containing a large proportion of water. When a ſmall quantity of borax is heated ſo as to diſſolve in its own water, it boils in a white foam; and when the water is diſſipated, the ſalt is found to have loſt much of its weight. By increaſe of heat, it undergoes a proper fuſion, and aſſumes the appearance of glaſs; but is diſtinguiſhed from that ſubſtance, by diſſolving and cryſtallizing again.

Borax may be decompoſed by means of the muriatic acid. It appears ſurprizing, but the fact is certain, that a quantity of acid of borax, though ſo weak an acid in its more obvious properties, will diſlodge, when heat is applied, both the nitrous and muriatic acids, and unite itſelf to their alkali. The reaſon ſeems to be, that the attraction of different ſubſtances for the ſame body is different in different degrees of heat. This again is to be attributed to a double elective attraction, in conſequence of the addition of the matter of heat. The coheſion of the nitrous and muriatic acids to their baſe, is ſo much weakened by their affinity with heat, or in other words, their tendency to aſſume the gaſſeous form, that the attraction of the boracic acid, which is more fixed, becomes ſuperior, and diſplaces them.

Borax, as imported from the Eaſt Indies, is very impure. When purified, it has a very regular form. Its cryſtals are ſix-ſided priſms, two of the ſides being commonly larger than the others, terminated by trihedral pyramids. Its cryſtallization is,

is, however, ſubject to conſiderable varieties. It is ſtyptic, and acts ſtrongly on the tongue, and like alkalies it converts the ſyrup of violets to a green. Borax, expoſed to the air, loſes a ſmall part of its water of cryſtallization, and ſlightly effloreſces. It is ſoluble in twelve parts of cold and ſix of hot water. Its cryſtals may therefore be obtained by cooling; but the fineſt and moſt regular are formed by ſuffering the cold ſaturated ſolution to evaporate ſpontaneouſly in the ordinary temperature of the atmoſphere.

Borax is exceedingly uſeful in many manufactures. It is employed as an excellent flux in the art of glaſs-making, as well as in aſſays. It is advantageouſly employed in ſoldering, which it aſſiſts by promoting the fuſion of the ſolder, by ſoftening the ſurfaces of the metals, and by defending them from the action of the air.

Very little is known of the combinations of the acid of borax with the vegetable and volatile alkalies.

The phoſphoric acid, and the acid of amber, are capable of combination with the alkalies; but the reſults of theſe combinations are ſo little known, that I ſhall paſs them over in ſilence, and haſten to the conſideration of the earthy and ſtony ſubſtances.

Some ſaline, earthy, and metallic ſubſtances, have ſuch a relation to each other, that they are ſeparated with great difficulty, and adhere after repeated ſolutions and cryſtallizations. This circumſtance has given riſe to another diviſion of ſalts, which

are denominated triple. As they do not, however, appear of ſufficient conſequence to be treated of under a ſeparate ſection, I ſhall merely enumerate them at the concluſion of the preſent The moſt remarkable examples of this kind are, mineral alkali with calcareous earth; common ſalt with magneſia; vitriolated magneſia with iron; alum with iron; viriolated copper with iron; vitriolated copper with iron and zinc; vitriolated iron with copper; vitriolated iron with zinc; vitriolated iron with nickel.

CHAP.

## CHAP. IX.

### EARTHS IN GENERAL.

*Five Kinds of Earth.—Definition of Earths.—Exceptions.—Other general Properties of Earths.—Calcareous Earth.—Magnesia.—Barytes.—Clay.—Flint.*

IT is now generally agreed among chemiſts and mineralogiſts, that all the earthy and ſtony ſubſtances which compoſe the ſolid parts of this globe, are ultimately reſolvable into five ſimple and original kinds of earth; namely, lime or calcareous earth, magneſia, barytes or ponderous earth, argill or clay, and ſilica or flint*. Theſe ſubſtances agree in the following properties, which may be conſidered as the characteriſtics of all earthy ſubſtances. They are nearly inſoluble in water, are uninflammable, have not the metallic ſplendour, and their ſpecific gravity, compared with that of water, is not more than five to one. This definition, however, like that of ſalts, is not ſo preciſe as to be beyond the reach of criticiſm; becauſe there are ſome earths perfectly ſoluble in water, though but in ſmall proportions, and there are many in the internal parts of the earth which afford the ſtrongeſt

* It has lately been ſuppoſed, that there exiſt ſeveral other diſtinct kinds of earth belonging to particular foſſils. This may very probably be the caſe; but experiments have not yet been ſufficiently multiplied to eſtabliſh the fact.

evidence that they have been in a ſtate of ſolution. But the definition, though not ſtrictly accurate, is proper in a general ſenſe. There is great difference of ſolubility between earths and ſalts, for a few grains of earth are ſufficient to ſaturate * a large quantity of water. There are two other circumſtances not included in the definition, which make part of the idea of an earthy ſubſtance; 1ſt, a great degree of fixedneſs; 2dly, a diſpoſition to form a glaſſy concretion when melted with other ſubſtances.

*Lime*, properly ſo called, is obtained by expelling the carbonic acid from calcareous ſubſtances by means of heat. *Calcareous earth* is in a tolerably pure ſtate in common quick-lime; but if it is required perfectly free from foreign admixture, it may be obtained by the following proceſs: If pounded chalk is ſeveral times boiled in diſtilled water, the remainder will conſiſt almoſt entirely of calcareous earth, combined with the carbonic acid. If diſtilled vinegar is added to the powder thus obtained, it will form a ſaline combination with the lime only, to the excluſion of all extraneous matter. To a ſolution of this, decanted from the impurities, mild volatile alkali being added, the alkali will unite with the vinegar, while the calcareous earth ſeizes the carbonic acid of the alkali, and falls to the bottom in the ſtate of a perfectly pure chalk. The carbonic acid may be driven off by heat, and cal-

* See note †, p. 1.

careous

careous earth is thus obtained in its most simple state.

The relative weight of quick-lime to that of slaked lime is as 1,000 to 1,287. Every pound can imbibe four ounces four drams and fifty-three grains of water.

Calcareous earth is soluble in the nitrous and muriatic acids, and forms deliquescent salts. It is precipitated from its solutions by means of vitriolic acid, with which it forms a nearly insoluble compound, called selenite, (or plaister of Paris.) Pure calcareous earth, or lime, is soluble in a small proportion in water, with which it contracts great heat. It is infusible without addition. It attracts the carbonic acid from the fixed alkalies, and by itself becoming mild renders them caustic. Its specific gravity is 2,723.

*Magnesia* does not burn into a caustic substance like quick-lime, though it is deprived of its carbonic acid by the application of heat. It is soluble in several acids, and forms with the vitriolic the sal catharticus amarus, or Epsom salt. When mixed with water, it shews a very small degree of heat, but without any effervescence. It requires 7,692 times its weight of water for its solution. It is not precipitated from other acids by the vitriolic, as calcareous earth is. Its specific gravity is 2,155.

*Barytes* is by far the most ponderous of the earths, from which circumstance it derives its name.

2 With

With vitriolic acid it forms the ponderous ſpar, which is inſoluble in water; and its combinations with the nitrous and muriatic acids are alſo not very ſoluble, but with the acetous acid (or vinegar) it becomes deliqueſcent. Combined with carbonic acid, it is ſoluble in 1550 times its weight of water, when pure in 900 times. The ſpecimens of barytes naturally combined with carbonic acid are rare; it is more commonly found united with the vitriolic acid. From this the earth may be ſeparated by the following proceſs: Pound the ponderous ſpar, and mix it with twice its weight of fixed alkali; expoſe this mixture to a ſtrong red heat for about two hours. The acid quits the earth to unite with the alkali, forming a neutral ſalt, which may be waſhed away. The earth remains combined with carbonic acid, which may be diſpelled by heat. The ſpecific gravity of this earth, when pure, is 3,773.

Argill, or *clay*, is ſoluble in the vitriolic, nitrous, and muriatic acids, and forms alum with the firſt of theſe. If concrete volatile alkali* is added to a ſolution of pure alum, the alkali and acid unite, while the clay falls to the bottom, united with only a ſmall quantity of fixed air. The fluid muſt be abſtracted by decantation, and the precipitate waſhed with diſtilled water, and dried. Pure clay does not become cauſtic by burning, but is contracted in ſize, and becomes very hard. The ſpecific gravity of this earth is only 1,669.

* The volatile ſalts in a ſolid ſtate.

The

The principal natural ſpecimens of argillaceous earth are boles, clays, marles, ſlates, and mica. In none of theſe, however, except the flag-ſtone, does the argill amount to half the weight of the whole ſubſtance. Silica abounds very much in common clays. Baked clays conſtitute all the varieties of bricks, pottery, and porcelain. If baked in a ſtrong heat, they give fire with ſteel.

Silica, or *flint*, is ſoluble in only one of the acids, the fluoric. In its indurated ſtate, it is always ſufficiently hard to ſcratch and ſtrike fire with ſteel. After being burnt, it does not fall to powder as the calcareous earth does. It produces no efferveſcence with acids. It may be diſſolved by the fixed alkalies, both in the dry and wet way. When alkali and flint are expoſed to the heat of a glaſs-houſe furnace, if the alkali is only half the weight of the ſilica, it produces a diaphanous and hard glaſs, but when the alkali is in double or triple the proportion, the glaſs deliqueſces of itſelf, by attracting the humidity of the atmoſphere; and forms what is called liquor of flints. This earth is perfectly diſſolved in that wonderful boiling water-ſpout, above ſixty feet high, at Geyſer in Iceland, where by cooling it forms a hard ſiliceous maſs. Pure ſiliceous earth is obtained by fuſing * clear quartz with four times its weight of fixed alkali, diſſolving the whole in diſtilled water, and precipitating the earth by an acid. Its ſpecific gravity is 2,650.

* Melting by heat.

Mr.

M. Bergman has formed perfect siliceous crystals by dissolving siliceous earth in the sparry acid, and suffering it to crystallise slowly. It is probable that nature forms them in a long course of time from a solution or diffusion of this earth in water.

Though the simple earths are all infusible alone, yet they may readily be fused by mixture with each other. The calcareous earth is found to act as a menstruum in dissolving the other earths by heat; and when it has once acted on any earth, a compound menstruum is formed, which acts still more efficaciously in dissolving other earths. Hence it is, that any three of the simple earths may be fused into glass, provided calcareous earth is one of the number.

Thus far it appeared necessary to premise concerning the general properties of the five simple earths in their separate state; but as their combinations are various, and their uses in this last state very important, it will be proper to treat of each on a more ample scale than the limits of a single chapter would admit.

# CHAP. X.

## CALCAREOUS EARTHS.

*Chalk.—Limestone.—Marble.—Marle.—Calcareous Spar.—Iceland Crystals.—Petrifactions.—Parts of Animals found in Marle, &c.—Gypsums.—Great Varieties.—Alabaster.—Fibrous Stone.—Mineral Glass.—Selenite.—Gypseous Spar.—Plaister of Paris; how prepared.—Fusible or Derbyshire Spar.—Spars, how formed.—Beautiful Appearances in different Caverns.—Metallic Combinations with calcareous Earth.*

CALCAREOUS earth is sometimes found in the form of powder, but more frequently in that of a concrete substance called chalk, which differs with respect to the fineness of its particles and firmness of texture.

1. Chalk consists of calcareous earth or lime, united with carbonic acid, and an union of the same principles also constitutes limestone and marble. These substances only differ from common chalk in their degree of purity, or in the manner of their aggregation, admitting of more or less polish. The different coloured veins in marble are produced by the admixture of other substances, (most commonly iron) unequally distributed through the mass.

2. Strata of marle also contain calcareous earth, more or less blended with a considerable proportion of clay and sand.

3. Calcareous earth is often found projecting into the interstices and crevices of rocks in a crystallized

tallized ſtate, and is then called calcareous ſpar. It is more or leſs tranſparent, and ſhivers into flat fragments of a rhomboidal figure. One variety is called Iceland cryſtals. They engaged the attention of Sir Iſaac Newton, by their remarkable quality of refracting the rays of light without ſeparating them into colours, ſo as to make a line drawn on paper appear double, when viewed through them. The Engliſh lead-mines are full of ſpars; their ſhape is in general a firm column, terminated at each end with a pyramid. Of theſe calcareous ſpars there are many varieties.

4. Calcareous earth appears in the form of animal and vegetable ſubſtances, petrified into ſtone by being expoſed to petrifying waters. Theſe fill up the pores of the ſubſtance with calcareous earth, and incruſt them. Hence we may conclude, that this earth is ſoluble in water, and is depoſited in certain circumſtances. The quantity of earth, however, contained in the water is very ſmall, and therefore the petrifactions are formed ſlowly. Thoſe organic bodies which reſiſt putrefaction moſt, are frequently found petrified, ſuch as bones, ſhells, and the harder kinds of wood; on the contrary, the ſoft parts of animals, which are very ſubject to putrify, are ſcarcely ever found petrified. Mr. Kirwan remarks, that petrifactions are moſt commonly found in ſtrata of marle, chalk, limeſtone, or clay; ſeldom in ſand-ſtone, ſtill more rarely in gypſum, but never in gneiſs, granite, baſaltes or ſhoerl; they ſometimes occur among pyrites and ores of iron, copper, and ſilver, and almoſt

almoſt always conſiſt of the ſpecies of earth, ſtone, or other mineral, which immediately ſurrounds them. Thoſe of ſhells are generally found neareſt the ſurface of the earth, thoſe of fiſh deeper, and thoſe of wood deepeſt. A very remarkable circumſtance is, that petrifactions are found in climates where their originals could not have exiſted. From the gradual and inſenſible concretion of this kind of matter from dropping waters, are formed the large pendulous columns hanging like icicles from the roofs and ſides of caves. The moſt remarkable are in the Peak of Derbyſhire. Sometimes they are found in the arches of old bridges, and ariſe from the water oozing through and carrying particles of lime with it. This earth ſo concreted is called ſtalactites, ſtone-icicles, or drop-ſtone.

5. The ſhells of all cruſtaceous animals, from the coarſeſt to the pearl which lines the ſhell of the oyſter, are all made up of this calcareous earth, with a ſmall quantity of animal gluten. Egg-ſhells are of the ſame nature, and thoſe marine bodies which, from their hardneſs and vegetable appearance, are called ſtony plants, ſuch as are all the ſpecies of coral, &c.

Marles, which have been already mentioned as containing calcareous earth, are generally divided into three kinds. Firſt, ſhell-marle; ſecond, clay-marle; third, ſtone-marle. The firſt is found in beds of conſiderable extent, and conſiſts of the remains of ſea and land ſhells; that which contains the ſea ſhells is commonly found in the greateſt quantity.

 Of

Of this kind is that of Paris, mentioned by M. Reaumur, which is about ten feet deep, and of great extent, consisting of oyster and other sea shells. The relics of land shells are those of snails; they have probably been carried by the current of some water, and deposited at one place, and the water being drained off, the shells remained behind. Beds of fresh-water shells are also found. Clay-marle is a calcareous matter, which when exposed to the air crumbles to dust; it is to be distinguished from common clay, by effervescing with acids, from the calcareous earth it contains. Stone-marle differs from clay-marle only in being much harder; but it differs from ordinary stone by breaking to pieces when exposed to the air.

It has been supposed by some respectable writers, that all these species of calcareous earth derive their origin from shells. Some marbles are evidently formed of shells, and those of Derbyshire exhibit this appearance in a remarkable manner. Coral is universally allowed to be the work of small animals of the polypus kind. The strata of limestone being also found so frequently united with shells and other marine substances, has induced the philosophers to whom I allude to believe, that the stone itself is altogether composed of shells, which at first mouldered into paste, and were afterwards pressed and concreted together. In one of the quarries of Italy, the bones of small fishes are found; and some rocks in the midland counties of England are almost wholly composed of the kind of shells called *entrochi*. The animals which produce the coral are here seldom to be found; but in other parts,

parts, as in Jamaica, the bottom of the ſea is entirely covered over with coral, and harbours are ſometimes ſtopped up with it. Sir Hans Sloane mentions a Spaniſh plate-ſhip, which was wrecked, and remained at the bottom of the ſea twenty-five years, being then fiſhed for, the treaſure, as well as the timber, &c. were covered with coraline concretions. Hence, this conſtant growth at the bottom of the ſea may in time produce beds and ſtrata of this kind of earth, which, according to circumſtances, may be converted into marle, limeſtone, marble, &c. Calcareous earths, united with carbonic acid, may be known under all forms, by efferveſcence with the mineral acids.

6. If vitriolic acid is poured on chalk, the carbonic acid is expelled, while the vitriolic unites with the calcareous earth, and conſtitutes a ſubſtance which has very little ſolubility. This is GYPSUM, ſelenite, or plaiſter of Paris, which exiſts in conſiderable quantities in nature. Gypſums are found in ſolid maſſes, very ſoft, and eaſily ſcraped with a knife. They are diſtinguiſhed from the combinations of calcareous earth with carbonic acid, by not efferveſcing with acids; and from other earthy bodies, by being by heat changed into a white powder, which when mixed with a large proportion of water, ſuddenly concretes into a ſtony maſs. They are moſt commonly found in the ſtrata of clay, ſometimes in thoſe of ſand, under the appearance of a whitiſh coloured maſs, but the ſmall pieces are tranſparent, and ſometimes have a red tinge. They are often compoſed of ſmall ſhining par-

ticles, like the grains of sugar, and when under this appearance they are particularly called gypsum. When hard, so as to admit of being cut into toys and figures, they are called alabaster. The second form under which they are found, is that of a fibrous structure of oblique crystals, which are parallel to themselves, but which cross the mass from the upper to the under surface. In this state they are called fibrariæ or fibrous stone by Dr. Hill. These differ much in size and regularity of concretion. The third species is composed of clear transparent plates like glass, in close contact with each other, but which may be separated. They split with a knife into fine plates, very flexible, though they cannot be bent without producing flaws. They are called glacies marina, and sometimes Muscovy glass, but improperly, as that is a different substance.

The fourth species is in the form of separate oblong crystals, which are called selenites: some are long and regular, like crystals of salt. The fifth species of gypseous spar is of a platey texture. Gypseous spar varies in compactness and transparency, is sometimes white, sometimes reddish, and is mixed with a greater or less quantity of other matter: sometimes we meet with it in crystals. The ores of metals are often found in this spar.

Sixthly, gypsum is often met with in waters of springs in a dissolved state; for we find by experiment, that it is soluble in water, though but in small quantity. When the water is evaporated, it is deposited in crystals very small, and which ap-

peat like a white powder; but by the microscope are found to be oblong regular concretions.

Margraff first shewed that all these species were composed of calcareous earth and vitriolic acid. He took a quantity of gypseous earth in a subtile powder, and boiled it for some time in a solution of fixed vegetable alkali; and upon examination, he found the calcareous earth at the bottom in an uncombined state, and in the solution a vitriolated tartar. He also composed an artificial gypsum of calcareous earth and the vitriolic acid, which had all the properties of a natural gypsum. From knowing the composition of these substances, we may sufficiently understand their properties, particularly that of being converted by a moderate heat into plaister of Paris. If the purer kinds are reduced to fine powder, and put into an iron vessel, by the time the vessel is heated the powder grows light, and is thrown into motion like a boiling fluid. There are also a variety of other earthy powders, which when moist give the same appearance; for the vapour rising up, makes its way through the powder, keeps it afloat, and agitates it like a liquid in a boiling state. This appearance continues till most of the water is evaporated. After this the powder becomes heavy, and lies at the bottom of the vessel as before heating. It is then prepared for plaister of Paris, for if a quantity of it is put into so much water as gives it the consistence of cream, it will soon become solid, and ring like a vessel of earthen-ware, or metal. It loses its

transparency by heat, and becomes white. The softer kinds are best for the plaister of Paris.

The explanation of all these phenomena is not difficult, when we consider the nature of gypsum, which being a saline compound, has all the qualities of a salt. In its natural state it is crystallized in consequence of its containing a quantity of water. Heat expels the water; which being again added, is attracted by the gypsum, and occasions a crystallization.

A more violent heat produces very little change, as the vitriolic acid adheres very closely to the earth. If these substances, however, are mixed in powder with a quantity of charcoal-dust, the whole of the acid may be dissipated, and the calcareous earth only left behind, and thus a particular phosphorus is formed. In this experiment the charcoal attracts the oxygen of the acid, which is by that loss rendered volatile, and is dispersed in fumes.

7. Calcareous earth is also found saturated with muriatic acid in sea-water and in salt-pits.

8. Calcareous earth, united with the fluoric acid, forms the fusible spar or fluor, which is commonly known by the name of Derbyshire spar. The texture of this compound is either sparry, or irregularly shattered or cracked. It is either transparent or opake; and the specimens are of a cubic, rhomboidal, polygonal, or irregular figure. The coloured spars have the property of emitting light when laid on a hot iron, or otherwise heated; but they lose this property by being made red hot. The

green

green spars are the most phosphorescent, but none of them exhibit this quality except when well warmed. They are scarcely harder than common calcareous spars, and therefore do not strike fire with steel. They do not melt by themselves; but very much promote the fusion of other stones, particularly the calcareous. They do not effervesce with acids, either before or after being submitted to the action of fire.

Mr. Whitehurst explains in the following manner the formation of sparry and stalactitical productions. When water impregnated with the sparry acid proceeds slowly through different strata of earths and minerals, it becomes charged with a variety of these substances in solution; and as it exudes gradually on the surface of caverns and fissures, the aqueous particles evaporate, and the sparry matter crystallizes in various forms, including in its own substance the heterogenous matters with which it is charged.

If the quantity of water thus impregnated, which exudes through the pores of the earth or stone, is not more than will easily evaporate in the ordinary heat of the atmosphere, a sparry crust is formed. If the quantity of water exuded exceeds the quantity evaporated, stalactites are produced in one instance, and tubes in another.

If a drop of water hangs from the roof, almost dropping, the aqueous particles evaporate from the surface sooner than from its interior parts. A crystallization therefore takes place on the surface, while the center remains fluid: the water thus de-

tained is continually increasing, and the tube gradually extends downwards. By this process, tubes are frequently formed of two feet in length, and one tenth of an inch in diameter. The appearance of caverns ornamented with these splendid productions exceeds that of the most laboured works of art: transparent columns, adorned with the most beautiful and vivid colours, disposed sometimes in the form of a honey-comb, sometimes in a more irregular arrangement: mirrors, reflecting the images of objects, tinged with a light shade of the most delicate colours, ravish the eye of the beholder. The pillars appear of various forms and sizes; sometimes arranged like a regular colonnade, and sometimes disposed with all the delightful irregularity of nature. The stalactites hang like icicles from the lofty roofs of these stupendous caverns, and are reflected back by the polished and glittering floors. Some of the most striking caverns of this kind are the grotto of Antiparos*, Poole's Hole, and Peak Hole in Derbyshire.

9. Calcareous

* The following is an account of this famous grotto, communicated by Magni, an Italian traveller, to the celebrated Kircher.—'Having been informed (says he) by the natives of Paros, that in the little island of Antiparos, which lies about two miles from the former, a gigantic statue was to be seen at the mouth of a cavern in that place, it was resolved that we (the French consul and himself) should pay it a visit. In pursuance of this resolution, after we had landed on the island, and walked about four miles through the midst of beautiful plains, and sloping woodlands, we at length came to a little hill, on the side of which yawned a most horrid cavern, that with its gloom at

9. Calcareous earth is found saturated with a particular acid, perhaps of the metallic kind, namely, the

at first struck us with terror, and almost repressed curiosity. Recovering the first surprise, however, we entered boldly; and had not proceeded above twenty paces, when the supposed statue of the giant presented itself to our view. We quickly perceived, that what the ignorant natives had been terrified at as a giant, was nothing more than a sparry concretion, formed by the water dropping from the roof of the cave, and by degrees hardening into a figure that their fears had formed into a monster. Incited by this extraordinary appearance, we were induced to proceed still farther, in quest of new adventures in this subterranean abode. As we proceeded, new wonders offered themselves: the spars, formed into trees and shrubs, presented a kind of petrified grove; some white, some green; and all receding in due perspective. They struck us with the more amazement, as we knew them to be mere productions of nature, who, hitherto in solitude, had, in her playful moments, dressed the scene, as if for her own amusement.

'But we had as yet seen but a few of the wonders of the place; and we were introduced only into the portico of this amazing temple. In one corner of this half illuminated recess, there appeared an opening of about three feet wide, which seemed to lead to a place totally dark, and that one of the natives assured us contained nothing more than a reservoir of water. Upon this we tried, by throwing down some stones, which rumbling along the sides of the descent for some time, the sound seemed at last quashed in a bed of water. In order, however, to be more certain, we sent in a Levantine mariner, who, by the promise of a good reward, with a flambeaux in his hand, ventured into this narrow aperture. After continuing within it for about a quarter of an hour, he returned, bringing some beautiful pieces of white spar in his hand, which art could neither imitate nor equal. Upon being informed by him that the place was full of these beautiful incrustations, I ventured in once more with him, for about fifty paces, anxiously and cautiously descending by a steep and dangerous way. Finding, however,

the tungſtenic acid. This combination forms the TUNGSTEIN of the Swedes. This ſtone is remarkably heavy,

however, that we came to a precipice which led into a ſpacious amphitheatre, if I may ſo call it, ſtill deeper than any other part, we returned, and being provided with a ladder, flambeaux, and other things to expedite our deſcent, our whole company, man by man, ventured into the ſame opening, and deſcending one after another, we at laſt ſaw ourſelves all together in the moſt magnificent part of the cavern.

'Our candles being now all lighted up, and the whole place completely illuminated, never could the eye be preſented with a more glittering, or a more magnificent ſcene. The roof all hung with ſolid icicles, tranſparent as glaſs, yet ſolid as marble. The eye could ſcarce reach the lofty and noble ceiling; the ſides were regularly formed with ſpars; and the whole preſented the idea of a magnificent theatre, illuminated with an immenſe profuſion of lights. The floor conſiſted of ſolid marble; and in ſeveral places, magnificent columns, thrones, altars, and other objects appeared, as if nature had deſigned to mock the curioſities of art. Our voices, upon ſpeaking or ſinging, were redoubled to an aſtoniſhing loudneſs; and upon the firing of a gun, the noiſe and reverberations were almoſt deafening. In the midſt of this grand amphitheatre roſe a concretion of about fifteen feet high, that, in ſome meaſure, reſembled an altar; from which, taking the hint, we cauſed maſs to be celebrated there. The beautiful columns that ſhot up round the altar, appeared like candleſticks; and many other natural objects repreſented the cuſtomary ornaments of this ſacrament.

'Below this ſpacious grotto, there ſeemed another cavern; down which I ventured with my former mariner, and deſcended about fifty paces by means of a rope. I at laſt arrived at a ſmall ſpot of level ground, where the bottom appeared different from that of the amphitheatre, being compoſed of ſoft clay, yielding to the preſſure, and in which I thruſt a ſtick to about ſix feet deep. In this, however, as above, numbers of the moſt beautiful cryſtals were formed; one of which,

heavy, and resembles fluor spar in the form of its fragments. It becomes yellow in acids, and is found united with petroleum (or mineral pitch) in the proportion of ninety-five of the former to four of the latter. In this state it forms the swine-stone, which is of a dark colour, and becomes fetid by friction.

10. Calcareous earth is also found united with three of the metals, iron, copper, and lead; of each of which there are several varieties. When united with copper, it is called mountain blue; when united with calx of copper, it is denominated Armenian stone. Gypseous earth combined with calx of copper, is called turquoise and malachites. The purest malachite, according to Kirwan, contains seventy-five parts of copper and twenty-five of aerial or carbonic acid; calcareous earth is therefore not an essential ingredient. It is of a green colour, and is sometimes cut and polished as a gem.

which, particularly, resembled a table. Upon our egress from this amazing cavern, we perceived a Greek inscription upon a rock at the mouth, but so obliterated by time, that we could not read it. It seemed to import that one Antipater, in the time of Alexander, had come thither; but whether he penetrated into the depths of the cavern, he does not think fit to inform us.'—*Kircher de Mund. Sub.* 112.

## CHAP. XI.

### MAGNESIAN EARTHS.

*Magnesia, how obtained.—Epsom Salt.—Soap Rock.—French Chalk.—Serpentine Stone.—Mica.—Talk.—Muscovy Glass.—Asbestos.—Mineral Cloth.—Mountain Leather.—Mountain Flax.—Mountain Wood.*

TO obtain MAGNESIA, the mother water of nitre, or of common salt, is placed in a large vessel, and diluted with a considerable quantity of common water. Fixed alkali dissolved in water is then added, and the mixture just made to boil. By this process the magnesia falls to the bottom of the vessel in the form of a powder, which is purified by repeated affusions of water. Magnesia, in its mild state, consists of forty parts magnesian earth, forty-eight carbonic acid, and twelve water. The crystallized aerated magnesia contains half its weight of carbonic acid, one fourth magnesian earth, and one fourth water.

Magnesia combined with vitriolic acid constitutes EPSOM SALT, which in many respects resembles Glauber's salt; it may be distinguished, however, by an easy experiment; for if a fixed alkali is added to a solution of Epsom salt, a precipitation is produced, which is not a consequence of adding an

alkali

alkali to a ſolution of Glauber's ſalt. Even the volatile alkali, if mild, is capable of ſeparating magneſia from its acid, by means of a double attraction; the alkali unites with the vitriolic acid, and part of the earth falls to the bottóm, combined with carbonic acid.

Magneſia enters into the compoſition of ſome earthy ſubſtances; the ſtones uſually treated of under this head conſiſt of magneſia united with flint; but the latter uſually predominates. Moſt of them are ſoapy to the touch, and ſo ſoft that they may be cut into various utenſils.—Of theſe the following are the moſt remarkable:

1. Steatites, lapis ollaris, or SOAP ROCK, is of various colours, but chiefly different ſhades of green. It does not become ductile in water, and is fuſed with difficulty. One variety of it is in the form of ſix-ſided priſms, another is lamellated.

2. Smectis, or FRENCH CHALK, is found pretty plentifully in Cornwall. Its colour is either white, yellow, or red and white; ſome ſpecimens have the appearance of Caſtile ſoap.

3. SERPENTINE STONE is of different ſhades of green. The ſtructure of this ſtone is fibrous, and it might therefore be confounded with another earthy matter, called aſbeſtos, if its fibres did not adhere ſo cloſely together, as to eſcape obſervation, when the ſtone is cut and poliſhed. Of the ſerpentine ſtone there are many varieties, and it is found ſpotted or ſtreaked with a great diverſity of colours. What is commonly called ſerpentine ſtone, is a true lapis ollaris; but being

being variegated like the ſkins of ſome ſerpents, is diſtinguiſhed by another name. Great quantities of this ſtone are found in Italy and Switzerland, where it is often worked into the ſhape of diſhes and other veſſels. It is harder than ſteatites, but not ſo hard as to give fire with ſteel; and leſs ſmooth to the touch, but is ſuſceptible of a good poliſh; it looks like marble, and is often in thin pieces ſemitranſparent. The greener ſorts of this ſtone have been called nephritic; their colour ariſes from manganeſe. But the term lapis nephriticus is commonly applied to jade.

4. Micaceous earths, or TALKS, may be defined earthy or ſtony bodies, the texture and compoſition of which conſiſts of thin flexible particles, diviſible into plates or leaves, having a ſhining ſurface. Theſe plates, by being expoſed to heat, ſeparate into ſmaller ones, but their flexibility is much diminiſhed. By a ſtrong heat they curl or crumple, but it is very difficult to reduce them to perfect fuſion without addition. The plates of mica, when of the pureſt kind, are tranſparent, and there is one variety, the plates of which, from their near reſemblance to glaſs, are called Muſcovy glaſs. Micas, however, are often tinged with a variety of colours, or are more or leſs opake. Sometimes they have a luſtre reſembling that of metallic ſubſtances. Sometimes they are in the form of ſhining powder, like that which is uſed in bronzing figures. This appearance has often impoſed upon miners, who have thought they met with gold and ſilver, whereas

there is never any metal in these substances but iron. They are found also mixed with other stones, as the granite, which frequently contains a great quantity of talk. Freestone also contains more or less; its horizontal layers have between them a thin stratum of talk where the stone more easily separates. It is also found in some kinds of slate, which, when exposed to the air, moulder into talky powder. The transparent Muscovy glass is used for windows, and for those lanthorns which are employed in powder magazines, as this substance is not so liable to break as glass, and is unassailable by fire. The twisted, or crumpled mica, which is found at Hardal in Jempland, is there manufactured into kettles and other vessels, as also for hearths of chimnies; and the powder which falls in the working may be mixed with common salt for the distillation of the muriatic acid. The shining appearance of the micaceous earths has obtained them the names of daze, glimmer, or glist. Talk differs from other micas in its laminæ or filaments being much tenderer and more brittle, but both have the metallic lustre.

5. The ASBESTOS, or amianthus, is a fossil agreeing with talk in having a regular structure, in being flexible, but differing in being composed of fibres instead of plates. When long exposed to air, it dissolves into a sort of downy matter, which has some degree of toughness, but the fibres of which connot be unravelled. Cloth and paper have been made of this substance, which resist the fire. Asbestos,

bestos, however, though unassailable by common fires, has submitted to the power of strong burning mirrors, and has undergone vitrification. The acnients are said to have manufactured cloths of this fossil, in which they wrapped their dead when they burned them, that the ashes might be preserved. Several moderns have succeeded in making this cloth; the chief contrivances which are necessary are to mix the mineral fibres with a large proportion of flax, and to use oil freely; these matters are afterwards consumed by exposing the cloth to a red heat. Although the cloth of asbestos when soiled is restored to its whiteness by burning; yet it does lose some part of its weight, as has been ascertained by accurate experiments. The varieties of this curious genus of fossils are mountain leather or cork; mountain flax, to which the name of amianthus is particularly applied; common or unripe asbestos, and mountain wood. These substances all consist nearly of the same component parts, and differ chiefly in colour, solidity, or in the form and direction of their fibres. Some specimens of the amianthus are so light as to float in water. When the fibres are parallel, it is called mountain leather; when twisted, mountain cork.

The mountain cork or leather contains in the hundred from 56 to 62 parts of siliceous earth, from 22 to 26 of mild magnesia, from 7 to 14 of mild calcareous earth, 1.7 of clay, and 10.6 of iron. These afford a white slag by fusion. The

specimens

ſpecimens which are of a yellowiſh *brown* colour are impure, and melt pretty eaſily into a black ſlag. There is alſo a ſpecies of a light green colour, ſomewhat more brittle, and contaminated with iron. This laſt is ſoluble by heat into a ſemitranſparent glaſs.

CHAP.

## CHAP. XII.

### PONDEROUS EARTHS.

*Barytes a scarce Mineral; found in two States.—Cristatum.—Ponderous Spar.—Cawk.—Liver Stone.*

BARYTES is but thinly scattered in nature. It is found in two states, combined either with the carbonic or vitriolic acids. 1st. When united with the former acid it resembles alum, but is hard and striated, as if composed of radiating fibres coming from a center. It is sometimes of a greenish colour; sometimes jagged, when it is called *cristatum*, from its resemblance to a cock's comb. These prominences are found accreted to balls of the same substance.

2. Ponderous earth is more frequently united with vitriolic acid. These stones are found of various appearances, pale yellow, blackish, with coarse scales, or with fine sparkling scales. They are either transparent or opake. The transparent PONDEROUS SPAR is usually in the form of a six-sided very flat prism, ending in a four-sided pyramid; but, like all other crystals, liable to be varied by the circumstances attending their formation. The opake specimens, called CAWK by the miners, are of a white, grey,

grey, or fawn-colour; frequently of no regular figure, but often in the peculiar figure of a number of ſmall convex lenſes united together. Theſe varieties are all remarkably heavy, in general exceeding four times the weight of water, and by this circumſtance the preſence of barytes may commonly be diſcovered. The ſtones compoſed of vitriolic acid and barytes may be known by their ſmelling like liver of ſulphur when rubbed. From this property they are called *lapis hepaticus*, and *leberſtein* (liver-ſtone) by the Germans.

## Chap. XIII.

### ARGILLACEOUS EARTHS.

*General Account of Clays or Argils.—Alum; its Composition.—Natural History of Alum.—Action of this Substance on other Bodies.—Uses of Alum in the Arts.—Lac Lunæ.—Porcelain Clay.—Manner of making different Kinds of Pottery.—Stone Ware.—Yellow, or Queen's Ware.—China.—Lithomarga.—Terra Lemnia.—Bole.—Zeolite.—Lapis Lazuli.—Tripoli.—Brick Clay.—Slate.*

THE argill, or earth of clay, is one of thoſe ſubſtances which abound moſt in nature. There are immenſe ſtrata of clays, and they make a part of every rich ſoil. The idea commonly entertained of clay, is that of a natural ſubſtance, the pureſt kinds of which are firm, and have a ſort of fatneſs or unctuoſity, and which by being rubbed by the finger receive a poliſh. When dry, they imbibe moiſture, ſo that when applied to the tongue it adheres to them. From their attraction for water, they are always found moiſt in a natural ſtate. If more water is added, they form a ductile paſte, which, when thoroughly burnt and dried, becomes hard, ſtony, and impenetrable to water. On the regular contraction which clay undergoes from the application of different degrees of heat, depends the conſtruction of a thermometer for meaſuring intenſe degrees

degrees of heat, and invented by Mr. Wedgwood*.

As clays when wrought together become impenetrable to water, they are made use of to retain water in ponds, &c. This is the reason that when cattle are allowed to tread a clayey soil in wet weather, the plants die that grew there; for the clay being previously mixed with the water, and being then compressed by the feet of the cattle, the ground is rendered too tough for the vegetables to spring up through it, especially when the clay thus trodden together is afterwards dried by the heat of the sun. Clays differ much in consistency. Some melt in the mouth, others are gritty, and get between the teeth. They are white, blue, grey, red, yellow, or black. Some are much less viscid than others. Some resist a very violent heat without undergoing any change; but most of them, in very intense heat, melt into a vitrified mass. Some of them effervesce with acids, others not. All these varieties have but one species of earth for their basis, and are nothing more than mixtures of pure clay with heterogeneous substances. Thus we often find strata, which contain a large mixture of sandy and gritty particles. All clays which are sandy, are so from sand, or calcareous earth: when mixed with the latter, they effervesce. The variety of their colour depends on an admixture of iron; though sometimes of inflammable matter. The clay becoming white in the fire, is the surest sign of its purity. We can actually extract iron from most of these clays, especially those which turn to a red colour, which colour is always

* See vol. i. p. 96.

 assumed

aſſumed by the calces or ruſt of iron. When they effervefce with acids, they claſs with marles. Clay, united with vitriolic acid, forms that common and well known ſubſtance called ALUM.

The Στυπτηρια of the Greeks, and the alumen of the Romans, was a native ſubſtance, and differed much from the ſalt of which I am now treating. The varieties mentioned by Dioſcorides refer to ſtalactites, which contained very little if any alum, and that completely enveloped by a vitreous matter. The deſcriptions of Pliny are ſtill more difficult to be underſtood, as he had not ſeen the ſubſtance which he deſcribes, but merely tranſcribed from others. The factitious ſalt which is now called alum, was firſt diſcovered in the eaſtern countries, but when, where, or by what means, is unknown. On account of its ſimilar aſtringency, and its uſe in the arts of tanning and dying, the new ſalt has retained the old name.

Among the moſt early works for the preparation of alum, was that of Roccho, a city of Lycia, now called Edeſſa, hence the appellation Roch alum (now commonly miſtaken for rock alum). In the neighbourhood of Conſtantinople, and other parts near Smyrna, were many alum-works. The Italians hired and made uſe of theſe, but about the fifteenth century introduced the art into their own country.

Bartholomew Perdix, or Pernix, a merchant of Genoa, who had often been at Roccho, diſcovered the matrix of alum in the iſland of Iſchia, about the year 1459, and eſtabliſhed a manufactory there; at the ſame time John de Caſtro made the ſame diſ-

covery

covery at Tolfa, by means of the ilex aquifolium, which he had alſo obſerved to grow in the adjacent mountains of Turkey; and his opinion was confirmed by the taſte of the ſtones. The attempts of the Genoeſe at Viterbium and Volaterre ſucceeded extremely well; inſomuch that an edict of Pope Pius II. prohibited the uſe of oriental alum.

Manufactories were eſtabliſhed in Spain, Germany, England, Sweden, &c. in the courſe of the ſixteenth century.

The proportion of the principles may be aſcertained in the following manner: the water is expelled by a gentle heat; the remaining maſs grows opake, ſwells, foams, and at length grows quiet, ſpongy, and friable; the quantity of earthy baſis is eaſily determined by precipitation with fixed or volatile alkali.

Mr. Pott firſt obſerved that when clay is mixed with vitriolic acid, and boiled a conſiderable time, the ſolution affords alum, though he obtained but little in this way. Margraff found that the vitriolic acid diſſolves one half or more of the pureſt clay; from the ſolution he obtained much alum, but always found it neceſſary to add a certain portion of alkaline ſalt before the alum would appear; and he could never obtain it without adding a greater quantity of vitriolic acid than was neceſſary to compoſe the alum. The other half, which did not diſſolve, he concludes to be a very fine ſand, or an earth of the flinty kind. The ſhorteſt way is to add a ſmall quantity of fixed or volatile alkali to the ſolution, which immediately becomes muddy,

the alkali attracting some of the superfluous acid, a powder precipitates, consisting of the crystals of alum.

The alum, however, which is employed in the arts, is not prepared in this way. Nature produces but a very small quantity of actual alum, and this is mixed with heterogeneous matters, or efflorescences, in various forms, upon ores during calcination, but rarely occurs crystallized. In this latter state, it is reported to be found in Egypt, Sardinia, Spain, Bohemia, and other places; it is sometimes generated in the aluminous schist of Lapland and West Gothland, by a spontaneous decomposition of the ore; besides it is found (but rarely) in mineral springs. Alum is mostly prepared from certain fossils, or ores of alum, as they are called. These ores are generally found in strata, which appear like indurated clays, of a dark black colour, and have a sulphureous smell. When exposed to the air for some time, they grow hot, swell, and crumble down into a powder, emit sulphureous fumes, and sometimes take fire. Some do not undergo this change merely from exposure to the air, but must be first burnt and washed, and then exposed to the air a good while before alum can be obtained. After they have been crumbled down in this manner, they are steeped in water; an alkali is then added, and the alum crystallizes and subsides.

These ores are evidently natural mixtures of clay and sulphur. By exposure to air, according to the old system of chemistry, it was supposed that the clay acted on the sulphur in such a manner as to

make

make it part with its phlogiston, whence they explained the production of heat. This fact, however, is now much better explained, according to the new system, by supposing that the oxygenous gas of the atmosphere is decomposed; and while the oxygen is absorbed by the sulphur (with which it forms vitriolic acid) the heat is set at liberty, and becomes sensible.

After a proper quantity of alkali has been added to the solution, it is crystallized in the common manner, that is by evaporation. The crystals are at first tolerably distinct, but of no considerable size. A great quantity of them being heaped together until they undergo a watery fusion, they unite into a mass, which is called roch alum, and in this form it is exposed to sale.

That accurate and attentive observer, Bishop Watson, in his Chemical Essays, relates, that being one day engaged, in evaporating something or other from a saucer made of Staffordshire yellow ware, he was surprised to see a white substance bubbling through a crack in the saucer; upon tasting it, he found it to be a salt, and, upon further examination, discovered that it was a perfect alum. The fire, he observes, was a very hot one, and it was made of coal cinders; the saucer was placed on the bar of the grate, and the alum, he conceives, was formed from the sulphureous acid of the cinders uniting itself with the clay, which enters into the composition of the yellow ware. He was informed that the vapour which, in some places, escapes from the coal-pits which are on fire in Staffordshire, forms

an alum whenever it meets with an argillaceous earth. This, he remarks, is conformable to the manner of making alum on the Solfatara, near Naples, where they place little heaps of argillaceous earths or ſtones over the crevices from which the ſulphureous vapour iſſues, in order that they may collect a greater quantity of alum.

This ſalt contains much water, hence it undergoes what chemiſts call the watry fuſion; after this there remains a ſubſtance called burnt alum, which contains the earth and vitriolic acid, with little or no water; this, if the heat is increaſed, does not melt, nor by heat alone can we ſeparate the whole of the acid, though ſome of it riſes; but the addition of any inflammable matter diſpoſes it to riſe in fumes, which are very ſulphureous. One hundred parts of cryſtallized alum contain thirty-eight of vitriolic acid, eighteen of clay, and forty-four of water.

The ſenſible qualities of alum ſhew it to be the oppoſite to borax, which is compoſed of the fixed alkali and a very weak acid; on the contrary, alum is the ſtrongeſt acid, combined with an earth which attracts it very weakly; ſo that the qualities of the acid are very little altered, for if we apply a ſolution of alum to the infuſion of litmus, it changes it to a red. The ſolution has alſo a manifeſt acidity, combined with another taſte which approaches to ſweetneſs. If an alkali is added, the earth is immediately precipitated, and this effect is not only produced by the fixed and volatile alkalies, but by magneſia and calcareous earth. Alum is often obtained from the liquor of the compound of iron and vitriolic acid.

The

The earth of alum will combine in excess to the salt when already formed. M. Beaumé boiled a solution of alum with the earth precipitated from another portion of alum, by means of fixed alkali; the earth was dissolved with effervescence, the filtrated solution had no longer the taste of alum, but that of a hard water, did not redden the tincture of turnsole, but converted syrup of voilets to a green. By spontaneous evaporation it afforded crystals, scaly and soft to the touch like mica; M. Baumé compares them to selenite. It is not easy to compose alum by adding vitriolic acid to this saturated salt, the mixture becoming acid, but not styptic. However, after spontaneous evaporation for three months, the solution afforded crystals of alum mixed with some micaceous scales, similar to those afforded by alum saturated with its earth.

Alum, heated with combustible matters, forms a substance which takes fire on exposure to air, and is called the pyrophorus of Homberg. This chemist, who published an account of the pyrophorus, in the year 1711, made experiments on human excrement, for the purpose of obtaining a colourless oil possessing the property of fixing mercury into fine silver: the inquiry produced many discoveries; the residue of this animal substance, distilled with alum, took fire on exposure to the air. Homberg repeated this experiment a number of times, and always with success. Lemery the younger, in the years 1714 and 1715, published two memoirs, in which he affirms, that pyrophorus

rus may be made with a great number of vegetable and animal substances heated with alum. But he did not succeed in his attempts to form it with some other vitriolic salts. These two chemists, who supposed alum to be a combination of the vitriolic acid and calcareous earth, imagined that the latter being converted into lime attracted the humidity of the air, and produced a degree of heat sufficient to set fire to the sulphur, formed by the vitriolic acid and inflammable substances.

Alum is one of the most useful salts in the arts. It is added to tallow to make candles hard. Wood sufficiently soaked in alum does not easily take fire: the same is true of paper impregnated with it, which for that reason is very proper to keep gun-powder, as it also excludes the moisture of the air. This paper is also useful in whitening silver, and in silvering brass without heat. Alum is useful added to milk which does not easily separate its butter.

It is particularly useful in dying, in preparing the matters to be dyed; for by cleansing and opening the pores upon the surface by a gentle corrosion, it both renders the substance fit for receiving the colouring particles (by which the alum is generally decomposed) and at the same time makes the colour fixed. It constitutes the basis of crayons, which generally consist of the earth of alum, finely powdered and tinged for that purpose, with different colouring matters.

The argillaceous fossils are referred to the following heads;

I. Argilla aerata, to which the fanciful name of lac lunæ has been applied. This was ſuppoſed to be a particular ſpecies of calcareous earth, till M. Screber found that it was a combination of argill with the carbonic acid. It efferveſces with acids, and contains a very ſmall proportion of calcareous earth, and ſometimes of gypſum. It is generally found in ſmall cakes of the hardneſs of chalk, like which it marks white. Its colour is ſnow white, and when examined by the microſcope it is found to conſiſt of ſmall tranſparent cryſtals. It efferveſces with acids.

II. Porcelain clay, argilla apyra, the *kaolin* of the Chineſe. This is ver, refractory, and is with great difficulty brought into perfect fuſion. After it has been ſubmitted to the action of heat, it is of a ſolid texture, and is ſo hard as to ſtrike fire with ſteel. It is found of an excellent quality in Japan, and likewiſe in different parts of Europe. In Sweden it is met with in coal-pits, between the ſtrata of coal. Common pipe-clay belongs to this diviſion, and differs from porcelain clay only in being leſs pure, which prevents its burning to a good colour.

The eſſential ingredient in all kinds of pottery is clay or argillaceous earth, becauſe theſe earths are capable of being kneaded, and eaſily receiving any form, and of acquiring much ſolidity and hardneſs by expoſure to fire. Pottery is, in general, covered with a glazing, or is made to undergo a vitrification at the ſurface, without which it would be pervious

to fluids. Ordinary pottery is glazed with glaſs of lead mixed with metallic calces, or with fuſible metallic earths. A fine kind of pottery is made of white clays, or ſuch as whiten in the fire; the ſurface of which is vitrified by throwing into the furnace, when the ware is ſufficiently baked, ſome common ſalt and ſaltpetre. The Engliſh ſtone ware is compoſed of tobacco-pipe-clay and ground flints. The uſe of the flints is to give ſtrength to the ware, ſo that it may preſerve its form during the baking. In making this ſtone-ware great pains are taken to employ only the finer particles of the clay and flint. With this view the clay is much beaten in water, by which the finer parts being mixed with the fluid are ſuſpended, while the coarſer ſink to the bottom of the veſſel. The thick liquid, conſiſting of water and the finer particles of the clay, is farther purified by paſſing it through hair and lawn ſieves of different degrees of fineneſs. After this the liquid is mixed, in various proportions for different wares, with another liquor, of about the ſame denſity, and conſiſting of flints calcined, ground, and ſuſpended in water. The mixture is then dried in a kiln, and afterwards, being beaten to a proper temper, it becomes fit for being formed at the wheel into diſhes, plates, bowls, &c. When the ware has been expoſed to heat for about forty-eight hours, it is glazed by means of common ſalt. This is thrown into the furnance through holes in the upper part of it, and being converted into a thick vapour by the heat, is applied to the ſurface of the heated ware, and cauſes it to vitrify. This curious

method

method of glazing earthen ware was introduced into England by two Dutchmen, near a century ago. It appears to be produced by a combination of the alkali of the salt with the siliceous earth of the pottery. The yellow or queen's ware is made of the same materials as the flint ware, but in different proportions. The glazing is also different; it is made by mixing together in water, till it becomes as thick as cream, one hundred and twelve pounds of ground white lead, twenty-four pounds of ground flint, and six pounds of ground flint glass. The ware, before it is glazed, is baked in the fire, by which it acquires the property of strongly imbibing moisture; it is then dipped in this composition, ahd suddenly taken out. It is afterwards exposed a second time to the fire, by which means the glaze it has imbibed is melted, and a thin glassy coat is formed upon its surface, which is more or less yellow, according as a greater or less proportion of lead has been used. Porcelain, or china, is a semivitrified earthen ware of an intermediate nature between common wares and glass. The first specimens of this beautiful manufacture came from China and Japan. Chinese porcelain is said to be composed of two ingredients, one of which is a hard stone or rock called *petuntse*, which they carefully grind to a very fine powder; and the other, called by them *kaolin*, is a white earthy substance, which they mix intimately with the ground petuntse. Reaumur examined both these matters; and having exposed them separately to a violent fire, he discovered that the petuntse had fused without addition, but that the kaolin had given no sign of fusibility; from

from which it appeared that the former was of a flinty nature, and the latter argillaceous. He afterwards mixed these matters, and formed cakes of them, which, by being baked, were converted into porcelain similar to that of China. Macquer thinks that the first European porcelains were made in Saxony and in France; and afterwards in England, Germany, and Italy. Manufactories have since been estalished in almost all the countries of Europe, in many of which porcelain is made very little if at all inferior to the Chinese.

III. Lithomarga, or STONE-MARROW, when dry, feels as slippery as soap, but is not wholly diffusible in water. When mixed with water, it falls in pieces, so as to assume the appearance of curds. In the fire it melts into a frothy slag. In the mass it breaks into irregular scaly pieces. This is the fuller's earth used in the dressing of cloths. To this species also belongs the terra lemnia; this is of a brownish colour and shining texture, and falls to pieces in water with a crackling noise. The terra lemnia is so called from the island of Lemnos, now Statimane, in the Ægean sea, whence it is procured. It is likewise called the Turkish earth, on account of its being impressed with the seal of the grand signior.

IV. BOLE is a fine and dense clay of various colours, containing a large quantity of iron. It is not easily softened in water when indurated, as the porcelain and common clays, but either falls to pieces in

in the form of fine grains, or repels the water, and cannot be made ductile. In the fire it grows black, and is then attracted by the loadstone. The soft boles are of various colours, as red, yellow, green, grey, and blueish grey. The red kind is that used in medicine, under the name of Armenian bole; an indurated kind of which affords the material for red pencils. An indurated bole is frequently found in coal-pits, between the seams of coal, and is called coal-slate. It is met with frequently in pieces like nuts of various sizes; which when broken exhibit impressions of plants, as the nodules of copper-slate from Ilmenaus contain representations of fish. A species of bole is found with scaly particles, the *hornblende* of the Swedes. It is distinguished from mica, by the scales being less shining, thicker, and rectangular. It is frequently mixed with pyrites; it is of two kinds, black and greenish. The former, when rubbed fine, affords a green powder, and is either of a lamellated or granular texture. The greenish kind is of a granular texture, or striated.

V. Zeolite is in general of a crystalline form, composed of imperfect pyramids turned towards a common center. Their form is sometimes globular, but seldom prismatic. The lapis lazuli belongs to the zeolites. These fossils are harder than fluors, but may be scratched by steel. The siliceous earth predominates much in them. The lapis lazuli contains silver and iron, which gives the blue colour. Zeolite melts *per se* with ebullition into a white frothy slag, which in the moment of fusion

fusion affords a phosphoric light. The lapis lazuli first becomes brown when melted, and then produces a clear glass with blue clouds. By scorification with lead, one hundred weight of it has afforded two ounces of silver.

VI. Tripoli seems to be of a volcanic origin. It is an earth consisting of very fine particles, and is known by its quality of rubbing or wearing hard bodies, which gives them a polish. Other fine clays, however, have the same property when a little burnt. The tripoli grows somewhat harder in the fire, and is fused with great difficulty. When crude it imbibes water, but is not soluble in it. It tastes like chalk, and is rough or sandy between the teeth, though no sand can be separated from it. That which has been just described is of a yellow colour, and is sold by druggists. This kind of tripoli has been lately discovered in Scotland. Another variety, called the rotten-stone, is found in Derbyshire. It is in common use in England for all sorts of finer grinding and polishing, and is also sometimes used by lapidaries for cutting of stones.

VII. Common or brick clay is found of various colours, as red, pale red, grey, and blue. It acquires a red colour, more or less deep, in the fire, and melts pretty easily into a greenish glass. It consists of a mixture of pure clay, siliceous and martial (or iron) earths, containing also a small quantity of vitriolic acid. The clay is also found mixed with calcareous earth, when it constitutes marle. It

is

is alſo found in an indurated ſtate, either pure or mixed with inflammable ſubſtances, and vitriolic acid, in which caſe it forms the ores of alum.

VIII. Argillaceous foſſile ſtones, to which the denomination of SCHISTI properly belongs. The moſt remarkable ſtones comprehended under this diviſion are the bluiſh purple ſchiſtus, or common roof ſlate; the dark blue ſchiſtus, or writing ſlate; the pyritaceous ſchiſtus; the bituminous ſchiſtus; the argillaceous grit, which is alſo called ſand-ſtone, and free-ſtone; the killas; the flag-ſtone, and the toad-ſtone.

The method of ſplitting the ſlate, uſed for the roofing of houſes, is the following: They expoſe it in blocks to be well wetted and ſoaked by the rain; when the froſt comes upon it afterwards, it rarifies the water, and cracks and opens all the joints of the ſtone, ſo that when the froſt has completed its work it lies in looſe flakes or ſhivers. Thus the elements perform with eaſe what no manual art could have eaſily accompliſhed.

## Chap. XIV.

### SILICEOUS EARTHS.

*General Arrangement of Flinty Substances.—Gems.—Diamond.—Ruby.—Sapphire.—Topaz.—Emerald.—Hyacynth.—Amethyst.—Garnet.—Tourmalin.—Opal.—Composition and Properties of precious Stones.—Quartz.—Rock Crystals.—Pebbles.—Flints.—Lapis Nephriticus.—Cat's-Eye.—Hydrophanes.—Explanation of the Phenomena of the Hydrophanous Stone.—Moon-Stone.—Chalcedony.—Onyx.—Carnelion.—Sardonyx.—Agate.—Common Flint.—Chert.—Sand and Gravel.—Jasper.—Feldt Spar.—Labrador Stone.—Schirl and Whetstone.—Art of making Glass.—Prince Rupert's Drop and Philosophical Phial.—Curious Phenomenon.*

THESE earths are chiefly distinguished by their hardness, by which they strike fire with steel, and their property of forming good glass with alkali. They may be divided into, 1, Gems, or precious stones; 2, Quartz; 3, Flints; 4, Jaspers; 5, Feldt-spars.

1. Gems.—The diamond is the hardest of all bodies. Its specific gravity is 3,445, hence it refracts the rays of light very powerfully; but it possesses this power even in a much greater degree than might be supposed from its density, and hence proceeds its singular brilliancy. The diamond, properly so called, is colourless; but it also retains this name when it is slightly tinged either with red or yellow. It is therefore not the colour of the stone, but its hardness

hardneſs and luſtre, which obtain it the denomination of a diamond.

Diamonds are found in the Eaſt Indies, particularly in the kingdoms of Golconda and Viſapour: they likewiſe come from the Braſils; but theſe laſt appear to be of an inferior quality, and are known in commerce by the name of Portugueſe diamonds.

Diamonds are uſually found in an ochreous yellow earth, under rocks of grit-ſtone and quartz; they are likewiſe found detached, in torrents which have carried them from their beds. Diamonds are ſeldom found above a certain ſize. The ſovereigns of India reſerve the largeſt, in order that the price of this article may not fall. Diamonds have no brilliancy when dug out of the earth, but are covered with an earthy cruſt, which incloſes a ſecond cruſt, of the nature of calcareous ſpar, according to M. Romé de Liſle. Bright diamonds are occaſionally found in waters.

Diamonds very often have no regular form, but are flat, or worn round. Sometimes they are regularly cryſtallized in octahedrons, formed by two quadrangular pyramids, united at their baſis; they are likewiſe found with twelve, twenty-four, and forty-eight faces.

Diamonds appear to be compoſed of laminæ, laid upon each other; and they are eaſily divided, by ſtriking them in the direction of theſe laminæ with a good ſteel inſtrument. There are, however, ſome diamonds which do not appear to be formed of diſtinct laminæ, but of twiſted fibres, like thoſe of knots in wood. Theſe laſt are exceedingly

hard, and cannot be wrought; lapidaries call them diamonds of nature.

Diamonds are ſhaped by firſt cleaving them in the direction of their lamellæ, and then rubbing them with other diamonds. They are then poliſhed by an horizontal ſteel wheel, duſted with their own powder mixed with olive oil.

2. The ruby has been confounded with the diamond, on account of its hardneſs and luſtre, but ſome late experiments ſhew that it is eſſentially different. According to Cronſtadt, there are four principal kinds of rubies:—1. The ruby of a deep colour inclining to purple. 2. The ſpinell ruby, of a ponceau red, that is, of a bright corn-poppy-flower colour. 3. The balaſs-ruby, pale red inclining to violet. 4. The rubicell, of a reddiſh colour.

3. The ſapphire is tranſparent, and of a blue colour, and is ſaid to be next to the diamond in hardneſs. They are ſometimes of a milky appearance.

4. The topaz is chiefly of different ſhades of yellow, but is ſometimes greeniſh. When of a ſea-green colour it is called aqua-marine; when more green, the beryl; when yellowiſh green, the chryſolite.

5. Emerald, the chief colour of which is green, is the ſofteſt of the precious ſtones, and when heated is phoſphoreſcent like the fluors.

6. The jacinth or hyacinth, is of a fine reddiſh yellow colour, and ſometimes brown; they are formed in priſms, pointed at both ends.

7. The

7. The amethyst is a gem of a violet colour, or great brilliancy, and as hard as the best kinds of rubies and sapphires, from which it only differs in its colour. This is called the oriental amethyst, and is very rare; when it approaches to the purple, or rose colour, it is more esteemed than when it inclines to the blue.

The amethysts called occidental, are of the same nature as rock crystals, and have the same gradations of colour. Crystals within the geodes, or hollow agate-balls, are very often found of an amethyst colour, and some are very fine.

8. The garnet, when transparent and of a fine colour, is reckoned among the gems; but it varies more than any, both with respect to its form and colour, some being of a deep and dark red, some yellow and purple, and some brown, blackish, and quite opake. The regular shape of the garnet is the dodecagon, with rhomboidal faces, and its chief variation is, the double eight-sided pyramid, terminating by four faces on each end. In general their lustre is less than that of other gems, as well as their hardness, which yields to the file, though they sometimes strike fire with steel. Their colour proceeds from the iron which they contain; and, according to M. de Saussure, even the finest oriental garnets attract the magnetic needle at a small distance. The Syrian garnet is the finest, and most esteemed: it is of a fine red, inclining to a purple colour, very diaphanous, but less brilliant than the oriental amethyst.

9. The tourmalin has lately been brought much

into notice by its remarkable property of becoming electrical, in consequence of the simple application of heat. If it is immersed in hot water, in which process no friction can be supposed to happen, after it is removed it gives signs of contrary electricity at the two opposite ends of its prismatic form.

The oriental tourmalins are found in the island of Ceylon: they are transparent, of a dark brown yellow. From Brasil they are for the most part green; but there are also some red, blue, and yellow. From Tyrol they are obtained of so dark a green, as to appear opake. They are also found in the mountains of Old Castile in Spain.

10. The opal is a most beautiful stone, from the changeable appearance of its colours by refraction and reflection. There are two kinds; one of which, the opal of Nonnius, appears olive-coloured by reflection, and then appears to be opake; but when held against the light, it is found to be transparent, and then appears of a fine red colour. The white opal, of a glass-like complexion, throws out green, yellow, purple, and bluish rays; but it is of a reddish, or rather flame-colour, when held against the light.

The precious stones are chiefly composed of the argillaceous and siliceous earths; of which the former predominates. The diamond is also thought to contain a peculiar earth, of different properties from those of any of the five earths above described.

On

On dissolving the very subtle powder of the gems in a double weight of vitriolic acid highly concentrated, the residuum, after evaporation, being washed with warm water, yields a metallic colouring substance, and a small portion of lime. The metallic part, precipitated by what was in the old chemical nomenclature called a phlogisticated alkaline lixivium, yields a beautiful Prussian blue; hence we conclude that the red colour of the ruby, as well as the blue of the sapphire, the yellow of the topaz, the tawny of the hyacinth, and the green of the emerald, are to be attributed to iron *.

Bergman obtained by analysis, from one hundred parts of the following precious stones:

| | Clay. | Flint. | Lime. | Iron. |
|---|---|---|---|---|
| Emerald, | — 60 | — 24 | — 8 | — 6 |
| Sapphire, | — 58 | — 35 | — 5 | — 2 |
| Topaz, | — 46 | — 39 | — 8 | — 6 |
| Hyacinth, | — 40 | — 25 | — 20 | — 13 |
| Ruby, | — 40 | — 39 | — 9 | — 10 |

From the above it may be collected, that the gems agree in this respect, that they all consist of the same principles; and that of these the argillaceous earth forms the greatest part, then the siliceous, next the calcareous, and least of all the iron †. The gems, except the emerald and hyacinth, resist the most intense fire; yet we know that the ruby

* Bergman's Dissertations, p. 15.
† Chemical Essays, Diss. 15.

has been ſoftened in the focus of a burning mirror *.

Theſe ſtones all aſſume different forms of cryſtallization, and as this affects the arrangement of their minute parts, it doubtleſs is not without effect on their external appearance. Their value depends on their hardneſs and tranſparency. The degrees of hardneſs are—1. diamond; 2, ruby; 3, ſapphire; 4, topaz; 5, hyacinth; 6, emerald.

The garnet differs from all the above, in the ſiliceous earth being more prevalent than the argillaceous.

II. QUARTZ has leſs tranſparency and hardneſs than the precious ſtones. The fracture of quartzoſe ſtones is vitreous, or like glaſs, and they ſtrike fire with ſteel. Heat cauſes them to loſe their hardneſs and tranſparency, and reduces them to a white opake earth. They are generally cracked throughout, and break irregularly, and into ſharp fragments. Melted with alkali they give a more ſolid and fixed glaſs than any others of the ſiliceous order. When there is no interruption to their natural accretion, their ſubſtance always cryſtallizes into hexagonal priſms, pointed at one or both ends. Theſe occur in clefts, fiſſures, and ſmall veins in rocks. Quartzoſe ſtones very often contain metals.

No very remarkable ſtones belong to this genus. The varieties are Fat quartz, which is very gloſſy; it is either colourleſs, or is tinged with white, blue,

* Chemical Eſſays, Diſſ. 15.

or

or violet. Dry quartz, tranſparent, white, or pale green. Spatry quartz, pale yellow, or pale blue. Cryſtallized quartz is either opake or tranſparent: the tranſparent and dark-brown kind is called ſmoky-topaz; the yellow, blue, green, and red, falſe gems; and the colourleſs, rock cryſtals; when milky, milk-cryſtals, and pebbles. Quartz is alſo found combined with iron and copper; with the former it conſtitutes a black calx, with the latter a red calx.

III. Flints are more uniformly ſolid, and not ſo much cracked in the maſs, as quartz; and are more pellucid than jaſper. They are better for making glaſs than the jaſper, but not ſo good as quartz, and ſeem in moſt reſpects to be of an intermediate nature between theſe ſtones. Flint often ſhews evident marks of having been in a ſoft and tough ſtate, like glue or jelly.

The ſeveral varieties of flints have obtained more diſtinct names, from the variety of their colours, than from any real difference in their ſubſtance; but theſe are ſtill proper to be retained, as the only names by which jewellers and others are uſed to diſtinguiſh them.

1. Jade, lapis nephriticus. This ſtone feels unctuous to the touch, but is ſo hard as to ſtrike fire with ſteel, and is alſo ſemipellucid. Theſe latter circumſtances ſufficiently denote its flinty nature; though its unctuoſity has induced ſome mineralogiſts to think that it ought rather to be referred to the argillaceous or magneſian orders. It is not hardened

hardened by the heat of the furnace, but it melts by the solar heat, in the focus of a burning mirror, into a green glass. That called by the name of circumcision-stone, which comes from the Amazon river, melts more easily by the concentrated rays of the sun into a brown opake glass. The colour of these stones is either milky, or different shades of green. Those of a grey, olive, or yellowish colour, are the vulgar lapis nephriticus; which name they have obtained, from a supposed property of curing nephritic pains, when applied externally to the loins. Their semipellucid appearance, hardness, and specific gravity, are characters by which the lapis nephriticus may be distinguished from other stones.

2. The cat's eye is a very scarce stone. It is opake, and reflects green and yellow rays, in a manner somewhat similar to the eye of the animal from which its name is derived. It is found in Siberia.

3. The Hydrophanes, or oculus mundi. The character which distinguishes this from all other stones is its property of becoming transparent in consequence of being immersed in water. This happens from its imbibing that fluid, as it becomes again opake by being dried.

This circumstance may be illustrated by a comparison with some other natural phenomena. The appearance of clouds serves to shew that particles of water, copiously mixed with those of air, prevent the transmission of light, and render the mass more or less opake, although the particles of

each,

each, separately taken, are pellucid. The cause of this is to be sought for in the difference of the refracting power; for, by means of that, the rays are turned from their original course at every particle, a circumstance which is very injurious to transparency. A common experiment will still more clearly elucidate this point. The most transparent glass, when reduced to powder, becomes opake, because the air which now occupies the interstices reflects the light much more copiously than the particles of glass. But upon pouring on water, which displaces the air, and which differs less from the glass in its refracting power, a certain degree of transparency is restored. On this principle depends the nature of the hydrophanous stone, which is opake when dry, but gradually acquires transparency by lying in water. This stone agrees nearly in specific gravity with water, at least is not more distant from it than glass. Its particles are transparent, but it is uniformly perforated by invisible foramina, so that the air and water are admitted, but not readily. When dry, therefore, on account of the great difference of the mediums between the particles of the stone and those of the air, it is opake; but when the water is gradually imbibed, it grows by degrees pellucid, beginning at the surface, and proceeding towards the centre. That the hydrophanes absorbs moisture and emits air, which is a fluid of much less density, appears from the weight it acquires, and the small bubbles which cover its surface during the time it is acquiring it transparency.

4. Moon-

4. Moon-ſtone, or rainbow-ſtone, reflects light of pearl and carnation colours. Its fracture is foliated, and its colour pale blue and milky.

5. Chalcedony, or white agate.—This ſtone is uſually cut with a convex ſurface, and receives a good poliſh. Its degree of hardneſs is intermediate, between that of the onyx and the true agate. It is ſemitranſparent, and its colour is uſually very ſimilar to that of milk diluted with water.

6. The onyx is the hardeſt of flints. Its uſual colour is that of the human nails. It is either marked with white lines only, or with black and white together. Heat deprives it of colour, and, if ſuddenly applied, cracks it.

7. The carnelion derives its name from its reſemblance to the colour of fleſh. It is either quite red or of different ſhades of red, with brown and yellow.

8. The ſardonyx is a mixture of the chalcedony and carnelion, ſometimes diſpoſed in ſtrata, and ſometimes confuſedly blended and mixed together. Its colours are therefore a mixture of white and red, ſometimes in ſtripes, ſometimes irregularly notched.

9. Agate. This name is given to flints that are variegated with different colours promiſcuouſly blended together, and they are eſteemed in proportion to the mixture and perfection of their colours.

10. Common flint or pebble, is in reality of the ſame nature with agate, but wanting the beautiful and various colours of the ſubſtances that bear that name.

name. Chalk and white lime-ſtone are uſually the matrices of flints, in which they are imbedded in the form of nodules, conſiſting of nuclei involved in a cruſt.

II. Chert is leſs hard and tranſparent than the common flint. It is not in general found in looſe and ſingle irregular nodules, but forms veins in rocks. Cherts are found of a fleſh-colour, white, pale yellow, and greeniſh, and ſeem to be of an intermediate nature between the flints and jaſpers.

Sand and gravel may be conſidered as flinty matters, torn away from the rocks in which they originally exiſted, and afterwards worn and ſmoothed by the attrition occaſioned by the motion of water. Sand and gravel, however, conſiſt of all the variety of ſtony matters which exiſted in the maſſes from which they proceeded, and are therefore found of many different colours and properties.

IV. The name of JASPERS is given to all the opake ſiliceous ſtones, which in their texture reſemble dried clay. The principal circumſtance, beſides their appearance, which diſtinguiſhes them from the other ſiliceous orders, is their more eaſily melting in the fire. They in general contain much iron. They are very hard, and admit a good poliſh; and they are variegated with different colours. They are ſeldom ranged in ſtrata, but form conſiderable maſſes and veins in rocks. They are alſo found in ſmall round maſſes. The principal ſpecies of jaſpers are the following—the white, grey, yellow, red, brown, green, veined, ſpotted, flowered, and green with

with red points, or blood-ſtone. Toys, and more eſpecially cups and ſaucers, are made of jaſper. Many antique ſculptures are in ſtones of this nature.

V. The moſt common kind of FELDT-SPAR is formed of rhombic laminæ, and has therefore obtained the name of rhombic quartz. It gives fire with ſteel, whence it has been called ſpathum ſcintillans. It is harder than the ſchiſti, and is fuſible. It is found in looſe maſſes, two inches long, or mixed with ſand, clay, &c. or bedded in granite. It is uſed in making china at Dreſden. Its colours are white, red, brown, pale yellow, or greeniſh.

The Labrador-ſtone is generally claſſed with the feldt-ſpars. It admits of a very fine poliſh, and when in that ſtate reflects a variety of beautiful colours. The ſtone itſelf is of different ſhades of grey.

VI. SHIRL or COCKLE, of different ſhades of green; and the various ſpecies of whetſtones, are alſo commonly referred to the ſiliceous order, though the latter are generally in ſome meaſure compound.

The uſes of the flinty ſubſtances are various, and have been partly intimated; but there is one art, in which their uſe is too conſpicuous to be paſſed over in ſilence.

The art of making glaſs depends on the fuſion of earthy ſubſtances, of which the flinty earth is the beſt, and for that reaſon is called vitrifiable. But as earths cannot eaſily be fuſed without mixture, it is neceſſary to add certain ſubſtances which may promote the vitrification. In the making of ordinary glaſs, two parts of ſand, or other ſiliceous matter,

ter, are mixed with about one of fixed alkali. If the glaſs is not required to be tranſparent, impure alkali, not freed from the aſhes, is employed; but in making the finer and moſt tranſparent kinds of glaſs, care is taken to purify both the earth and the alkali. One of the chief points to be obſerved in the making of glaſs is to heat the mixture gradually, ſo that the elaſtic fluids may eſcape before the materials cohere, as the ingredients are otherwiſe apt to be ſo ſwelled by the diſengagement of air as to be loſt by flowing over the ſides of the veſſel in which they are heated. In order to prevent this, due proportions of ſand and alkali are mixed together, and expoſed, during a conſiderable time, to a red heat, not intenſe enough to melt them. By this calcination the inflammable matters, which would have impaired the colour of the glaſs, are conſumed, and the air expelled. This firſt mixture of the materials of glaſs, after being treated in this manner, is called the *fritt*.

The due degree of heat is an eſſential point in making of glaſs: it ought not only to be very ſtrong, but alſo maintained during a long time. In great manufactories the glaſs is kept fuſed during ten or twelve hours before it is taken out of the pots. The ingredients are thus more completely melted, and more thoroughly mixed, and the appearance of threads or veins is in ſome meaſure prevented, which proceed from the different denſity of different portions of the glaſs, and which therefore act differently on the rays of light. The imperfections of glaſſes are moſt

moſt ſenſibly felt in the conſtruction of optical inſtruments.

Good glaſs, although kept in fuſion for a long time in a great heat, is never perfectly liquid. It is always ſomewhat thick, and when taken out may be drawn into fine threads. The great ductility and flexibility of red hot glaſs fits it for being reduced into any form. In general the glaſs is taken out of the pots in which it is fuſed by means of an iron tube. When a ſufficient quantity of the glaſs is collected at the extremity of the tube, the workman begins to blow thro' it, and thus inflates the glaſs. He occaſionally rolls it, in order to form it into a cylinder, a cone, &c. and if it becomes too cold, he heats it by holding it before the mouth of the furnace. Glaſs, in its tough ſtate, may be cut with ſhears, bended with pincers, preſſed into moulds, and wrought, in a variety of methods dependent on theſe properties, into the vaſt variety of forms which it is made to aſſume. Glaſs veſſels, as ſoon as made, are carried to an oven, in which they are gradually cooled; for without this proceſs, which is called *annealing*, they would either break in the cooling, or be liable afterwards to be broken by the ſlighteſt force.

The principal defects of glaſs are colours, veins, and bubbles. The colours which generally injure the common alkaline glaſs are ſhades of green, blue, and olive. Theſe are moſt effectually removed by the addition of a ſmall quantity of mangeneſe. The cauſe of the veins has been already explained, and that of the bubbles depends on the imperfect expulſion of air.

There

The addition of calx of lead to glaſs renders it much more denſe, and leſs liable to be broken. Artificial gems are only the beſt kinds of glaſs, coloured with different metals; but the modes of applying the ſeveral metals to this uſe will be mentioned when treating of them.

There are two toys made of unannealed glaſs, which, though commonly uſed for the amuſement of children, exhibit phenomena which juſtly intereſt the curioſity of the philoſopher. When a drop of melted glaſs is ſuffered to fall into water, it aſſumes an oval form, with a tail or neck reſembling the retort of a chemiſt. This is called Prince Rupert's drop, and poſſeſſes the ſingular property, that if the ſmalleſt portion is broken off, the whole drop flies into powder with a kind of exploſion, and a conſiderable ſhock is communicated to the hand that graſps it*. The other is called the philoſophical phial, which is a ſmall cylindrical veſſel of glaſs, open at the upper end, and rounded at the bottom. It is generally made of glaſs ſo thick that it will bear a ſmart blow againſt a hard body without breaking, but if a ſmall pebble or piece of flint is let fall into it, it immediately cracks and flies in pieces. This veſſel is formed upon ſimilar principles with Prince Rupert's drop, it conſiſts of glaſs ſuddenly cooled, and, I ſuſpect, by immerſion in water.

* Honour is like that glaſſy bubble,
That gives philoſophers ſuch trouble;
The one part crack'd, the whole will fly,
And wits are crack'd to find out why.

HUDIBRAS.

Various explanations have been offered of these facts. The most generally received is founded on the assumption that the dimensions of bodies which are suddenly cooled remain larger than if the cooling had been more gradual. The dimensions, therefore, of the smooth external surface of these glasses, which are suddenly cooled, are supposed to be larger than is adapted to the accurate envelopement of the internal part, which is necessarily cooled in a more gradual manner; if, therefore, by a crack or rasure, a solution of the continuity takes place in the external surface, the sudden action of the parts which remained in a state of tension, to recover that of perfect cohesion, is supposed to effect the destruction of the mass.

This explanation I confess has not appeared to me satisfactory, and I have been inclined to suspect that the phenomenon arises either from a quantity of air being included in the substance of the glass, which rushes suddenly out, on the surface which includes it being broken; or that by the sudden cooling the pores of the glass are sealed up by the fine smooth surface, and contain little or no air, so that on the continuity of that surface being interrupted, the air suddenly rushing into all the pores of the glass may effect its dissolution. That the whole effect depends on destroying the continuity of the surface, I have sufficiently proved; for unless the flint or pebble which is let fall into the philosophical phial is large and angular enough to scratch the surface of the glass, it will not break. To ascertain whether the fracture of these toys depends or not upon the

the air, a few experiments might be made on Prince Rupert's drops in a vacuum; when, if it proceeds from air included in the drop, the explosion will be more violent, or the drop would, perhaps, spontaneously burst; and if from the contrary cause, it will not break at all in vacuo.

I know not whether I am correct in introducing in this place a kind of mineral substance called *slickensides*, which is mentioned by Mr. Whitehurst *, as I am not even certain that it belongs to the siliceous genus, but the similarity in the phenomena which it exhibits to those of the Rupert's drop and the philosophic phial must be my apology. It may be a volcanic production, and may have undergone a sudden cooling, from some accidental cause similar to that of the glass of which I have been treating.

This stone has the appearance of black marble, and breaks where the explosion happens with a polished surface, not truly plane, but lying in waves. It is found in fissures of lime-stone in Haycliff and Ladywash mines at Eyam, and in Oden at Castleton, in Derbyshire. It is divided into two equal parts or slabs, by a line parallel to the sides of the fissure, and these slabs are joined by two polished faces, which seem to be in perfect contact without any cohesion. The surfaces are coloured with lead ore, or a substance very much resembling it, but as thin as a covering from a black lead pencil. If a sharp-pointed tool, which the workmen call a

* Observations on the Strata in Derbyshire, p. 185.

pick, is drawn over the vein with ſome force, the mineral begins to crackle like ſulphur excited by electricity; in a few minutes after which the laminæ explode with violence, and fly out as if they had had been blaſted with gun-powder, inſomuch that the weight of forty tons has been blown out together. Theſe dangerous effects deterred the workmen from proceeding for ſeveral years; but at length it occurred to them that this power might be uſed for the carrying on of their works with better advantage than by the common method of blaſting with gun-powder. Accordingly a workman makes a ſcratch with his tool upon the joint of the ſlickenſides, and runs away as faſt as he can, to eſcape the exploſion; which, it is ſaid, looſens as much of the rock as ten men would have brought away in three months, by the ordinary methods.

# CHAP. XV.

## COMPOUND EARTHS.

*Definition of this Genus.—Various compound Stones.*

IN a ſtrict ſenſe all earths and ſtones, as they exiſt in nature, may be denominated compound, as there are none which are wholly ſimple. By compound earths, however, is here meant ſuch as are formed of two or more kinds of ſtony matter, and which in general conſtitute a maſs of an heterogeneous appearance. In treating of theſe ſubſtances, the arrangement of M. Daubenton appears the moſt perfect and commodious.

### *Mixed Stones,*

#### OF TWO GENERA.

| | |
|---|---|
| Quartz and ſcintillating ſpar - | Granitin. |
| Quartz and ſchirl - - - - - | Granitello. |
| Quartz and ſteatites - - - | Quartzoſe ſteatites. |
| Quartz and mica - - - - - | Micaceous quartz. |
| Tranſparent quartz and mica - | Micaceous cryſtal. |
| Quartz in grit and gem ſtone - | 1 Garnet on grit ſtone.<br>2 Garnet in grit ſtone. |

| | |
|---|---|
| Quartz in grit and mica - - | Micaceous grit. |
| Quartz in grit and calcareous matter - - - - - - | 1 Cryſtallized grit.<br>2 Grit in ſtalactites. |
| Quartz in ſand and opake ſtone - - - - - - - | ſandy and ſiliçeous breccias. |
| Quartz in ſand and ſchiſtus | ſcintillating ſchiſtus *hornſtone. trap.* |
| Quartz in ſand and zeolite - | ſcintillating zeolite. |
| Scintillating ſpar and paſte, or cement, of ſchirl - - | ophites. |
| Semi-tranſparent ſtone, with opake ſtone - - - | jaſpered agate, or agatized jaſper. |
| Schorl and mica - - - | micaceous ſpathoſe ſchirl. |
| Schiſtus and mica - - - - - | micaceous ſchiſtus. |
| Schiſtus and marble - - - | Florence marble. |
| Serpentine and marble - | 1 green Egyptian marble.<br>2 ſea-green marble.<br>3 green antique marble.<br>4 green marble of Suza.<br>5 green marble of Varalta. |
| Ponderous ſpar and calcareous matter - - | alkaline ponderous ſpar. |

OF THREE GENERA.

| | |
|---|---|
| Quartz in ſand, ſchiſtus, and mica - - - - - - - - | Rough whet-ſtone. |
| Quartz, gem, and mica - - | garnet rock. |
| Quartzoſe paſte, ſcintillating ſpar in large fragments, and ſchorl | porphyry. |
| Quartzoſe paſte, ſcintillating ſpar in large fragments, and ſchorl | ſerpentine. *hard ſerpentine.* |

Quartz,

| | |
|---|---|
| Quartz, ſchirl, and ſteatites - | tuberculous rock. |
| Quartz, ſcintillating ſpar, and ſchirl - - - - - - - | granite. |

OF FOUR GENERA.

| | |
|---|---|
| Quartz, ſcintillating ſcar, ſchirl and mica - - - - - - | granite. |
| OF SEVERAL GENERA, MORE OR LESS IN NUMBER, UNITED IN BRECCIAS - - - - - - | univerſal breccias. |

DOUBLE BRECCIAS.

Varieties.
1 Fragments of porphyry, with a paſte of porphyry.
2 Fragments of granite, with a paſte of ſchorl.

## Chap. XVI.

### VOLCANIC PRODUCTS.

*Lava.—Different Kinds.—Progress of a River of Lava.—Compound Parts of Lava.—Pumice Stone.—Basaltes.—Trapp.—Terra Puzzolana.*

I. LAVA is of very various appearance, according to its composition, and its more or less perfect vitrification. The materials of which lavas consist, are the common substances to be found every where in the earth, namely, stones, metallic ores, clay, sand, &c.; and as there is room for great variety in the combinations of these substances, the melted masses formed by them must in different circumstances be very various. Some lavas are very compact, and receive a beautiful polish, exhibiting great variety of colours and forms. Others are extremely porous, and mixed with scoriæ or dross. On the different consistence of lavas depends their capacity for being converted into mould, capable of supporting vegetables. Some lavas have a tendency to crumble into dust immediately on issuing from the crater; others are a perfect glass, and are calculated to resist for a long time every approach towards dissolution.

Lava, when first thrown out from the crater of a volcano, is an uniform liquid mass, and flows down the

the ſide of the mountain with conſiderable rapidity. From loſs of heat, however, its ſurface is ſoon converted into a tough and black cruſt, which, as it becomes thicker, gradually impedes the progreſs of the fluid lava which is contained within it. This cruſt is frequently broken, when the ſtream of lava reſembles a river with maſſes of ice floating on its ſurface. Fluid lava ſometimes flows for a conſiderable diſtance, under the tenacious ſcum, and again appears beyond it in all its ſplendour. In the night time the courſe of the lava appears like flame, but no real flame ever exiſts, unleſs the lava in its progreſs happens to meet with combuſtible matter. In the day-time its courſe is marked by a thick white ſmoke.

Mr. Kirwan divides lavas into three kinds, the cellular, the compact, and the vitreous. All lavas are more or leſs magnetic, give fire with ſteel, are of a granular texture, and melt without the addition of other ſubſtances. The cellular lavas are ſuch as have undergone only the firſt and loweſt degree of fuſion, being juſt ſoftened and heated ſufficiently to expel the fixed air contained in the matter from which they are formed, which ſeems to be argillaceous ſlate; hence they abound in ſmall cavities occaſioned by the expanſion of that air. The ſpecific gravity of ſome lavas from theſe cavities is ſo ſmall, that they float for ſome time on water. From this circumſtance they have ſometimes been miſtaken for pumice-ſtone; but they differ from it, becauſe their texture is never filamentous. The perfectly vitrified lavas muſt have been expoſed to an

immenſe

immenſe heat, as they are very difficultly fuſed without addition. M. Sauſſure has ingeniouſly imitated all the different kinds of lavas, by different degrees of fuſion of the earthy ſubſtances from which they are formed. M. Bergman analyzed a ſpecimen of the perfect kind, and found an hundred parts to conſiſt of forty-nine of ſiliceous earth, thirty-five of argillaceous, four of calcareous earth, and twelve of iron.

The beds of lava are deepeſt and narroweſt near the crater, and broader and ſhallower as they advance, unleſs ſome valley intervenes. Pumice-ſtones lie at a ſtill greater diſtance; and from theſe obſervations, ſays Mr. Kirwan, extinguiſhed volcanoes may be traced. The quantities of matter thrown out of volcanoes at one eruption, are often ſo great as to cover a ſpace of country of many miles, and to be many years in cooling.

II. Pumice-stone ſeems to be rather a volcanic ejection than a volcanic product. Its colours are grey, white, and reddiſh brown. It is hard, rough, porous, conſiſts of ſlender fibres parallel to each other, is very light, and with difficulty gives fire with ſteel. It ſeems to have been originally an aſbeſtos decompoſed by the action of fire. One hundred parts contain from ſix to fifteen of magneſia, with a ſmall portion of calcareous earth; the remainder is chiefly ſilex. Pumice-ſtone ſwims on water. It is uſed to ſmooth rough ſurfaces, and, in a ſtate of powder, in various branches of manufacture, chiefly for poliſhing.

III. Ba-

III. BASALTES is a ſtone of a dark grey colour, covered with a ferrugineous cruſt, and generally cryſtallized in opake triangular or polyangular columns. When it is amorphous*, and breaks into large, thick, ſquare pieces, it is called *trapp*. When heated red hot, and quenched in water, it becomes by degrees of a reddiſh brown. It melts without mixture into a perfect ſlag. One hundred parts contain fifty-two ſiliceous, fifteen argillaceous, three calcareous, two of magneſian earth, and twenty-five of iron. Baſaltes ſometimes is found in large columns with convex and concave articulations, ſo as to reſemble an artificial ſtructure: of this kind are the baſaltic pillars in Ireland, called the Giant's Cauſeway.

Glaſs, in cooling, has been known to aſſume the regular baſaltic form. Sir William Hamilton remarked, both in Sicily and Naples, that ſuch lavas as have run into the ſea are either formed into regular baſaltes, or have a great tendency to that form.

IV. TERRA PUZZOLANA or Terras, is a volcanic production, of a grey, brown, yellowiſh or blackiſh colour, looſe, granular, or duſty and rough, porous and ſpongy, reſembling a clay hardened in the fire, and then reduced to a groſs powder. Its moſt diſtinguiſhing property is, that when mixed with about one-third of its weight of lime and water, it hardens very ſuddenly, and forms a cement which is more durable in water than any other. Its indurating power ſeems to ariſe from the dry ſtate of the half-baked

* Not of a regular form.

argillaceous

argillaceous particles, which caufes them to imbibe water very rapidly, and thus the deficcation of the calcareous earth is accelerated. It is found not only in Italy, but alfo in France, in the provinces of Auvergne and Limoges, and alfo in England and elfewhere. According to Bergman's analyfis, one hundred parts contain from fifty-five to fixty of filiceous earth, nineteen or twenty of argillaceous, five or fix of calcareous, and from fifteen to twenty of iron.

# CHAP. XVII.

## METALS.

*Uses of Metals.—Their Properties.—Weight, Opacity, Malleability, Ductility, Fusibility.—Mix with each other.—Their Inflammability.—Calcination.—Entire and Semi-metals.—Perfect and imperfect.—Natural History of Metals.—Working of Mines.—Assaying.—Smelting.—Union with Acids.—Action of other Substances on Metals.*

METALLIC substances are valuable for their durability, their capacity of assuming and retaining all sorts of forms and impressions; the closeness of their texture, which renders them capable of polish; the firm cohesion of their particles, which renders them highly proper for utensils, where great strength is required to be combined with moderate bulk. Several of the metals are also highly useful as medicines.

The first and most obvious property of metals is their remarkable weight, in which they exceed all other bodies. By this circumstance they are distinguished from earths; the lightest of metals, which is tin, being seven times the weight of water, whereas the heaviest earth is only between four and five times the weight of water.

Metallic substances are by far the most opake of all bodies. The most opake stone divided into thin

thin plates, has more or leſs of tranſparency, whereas gold is the only metal which admits of being reduced to ſuch a degree of thinneſs as to afford the ſmalleſt perceptible tranſmiſſion of light. Gold in leaf, which is about $\frac{1}{230000}$ part of an inch in thickneſs, tranſmits light of a lively green colour; but ſilver and braſs leaf are perfectly opake. The opacity of metallic bodies renders them exceedingly proper for reflecting the rays of light, as no bodies poſſeſs this property in ſo eminent a degree. Thus we obſerve that glaſs reflects objects very imperfectly, unleſs coated with metal, as in looking-glaſſes. The capacity of reflecting light depends on the degree of poliſh and the whiteneſs of ſurface, conſequently white metallic ſubſtances reflect a greater quantity of light, and are more brilliant, than thoſe which are coloured.

A property which ſeems to belong excluſively to metals, and yet not to all of them, is malleability. This conſiſts in a capacity of having their ſubſtance extended, and their ſurface increaſed, either in breadth or length, without being liable to fracture. The capacity, however, of being extended in length and breadth is not exactly the ſame, for metals which admit of extenſion under the hammer cannot always be drawn into wire, which property is diſtinguiſhed from the other by the term ductility. Beating always reduces metals to a ſtate of rigidity and brittleneſs. To remedy this, the metals are generally heated red hot, and cooled again ſlowly; in this caſe their malleability will be increaſed, and this is called annealing them. Crammer ſays, that

if gold is annealed in this manner the leaf will be opake, and that the tranſmiſſion of light through ordinary gold leaf depends on ſmall cracks and flaws in the metal. If this aſſertion is true, it will in a great meaſure eſtabliſh the perfect opacity of metallic ſubſtances. Metals, when hammered, give out a degree of heat, and at the ſame time become brittle; and the only method of reſtoring their malleability is to expoſe them to the action of heat, and to ſuffer as much of this as poſſible to fix itſelf in their ſubſtance, by cooling them gradually. From theſe facts it is probable that the malleability of metals, as well as fluidity and elaſticity in general, depends on the particles of bodies being kept at a diſtance by the preſence of latent heat.

Metals are the beſt conductors of electricity of all bodies.

Metals are fuſible by heat, and one of them (mercury) is well known to exiſt in a ſtate of fuſion in the ordinary temperature of the atmoſphere. The particles of metals have a remarkably ſtrong attraction for each other, which is evinced by ſmall portions of metal, when in a ſtate of fuſion, having a tendency to aſſume a globular form.

Moſt metals will uniformly mix in all proportions with each other; the ſpecific gravities, however, of theſe compounds is ſcarcely ever ſuch, as would be mathematically deduced from the ſpecific gravities of the metals employed, on the ſuppoſition of their junction by ſimple contact. Mixtures of metals are more fuſible than might be expected from the degree of fuſibility of their component parts,

parts, and are therefore conveniently used as solders.

It is found that metals which, after having been fused, are suffered to cool gradually, evince a tendency to assume a regular figure, and to crystallize in general in an octahedral form.

Metals, in their splendid or *reguline* state, have a considerable attraction for oxygen, and are in this respect nearly allied to the inflammable substances. Iron burns with a bright flame when heated to a certain degree, and immersed in vital air; and a mixture of tin and nitre produces a violent deflagration. Zinc, when heated and acted on only by common atmospheric air, burns with a bright and vivid flame like phosphorus. It is remarkable that mixtures of metals calcine more easily than the metals in a separate state. Thus a mixture of lead and tin, neither of which, when separate, afford heat and light, in their mixture produce both, and the calcination is remarkably rapid. From the addition of oxygen the weight of the calx is greater than that of the quantity of the metal from which it was produced. In some metals, however, the attraction for oxygen is so weak (as is the case with the finer metals) that it is only by particular processes that they can be combined with it. Metals united with oxygen lose their splendour, malleability, and texture, and are denominated calces.

According to the old chemical theory, the calx of a metal was deemed a simple substance, and was called the earth or basis of a metal; and it was supposed that this earth, united with phlogiston, constituted

tuted the metal in its perfect state. It is now, however, very satisfactorily proved, that the metallic state is the more simple, and that the calx is a combination of the metal with oxygen. Metals are reduced from the calciform to the reguline * or metallic state, by heating them in contact with substances which have a stronger attraction for oxygen than themselves, as charcoal, tallow, &c.

Metals which are malleable are called entire metals; and those which are brittle, semi-metals. Metals are also distinguished into perfect and imperfect. The perfect are such as are not calcined by being heated in contact with air, and are three in number, silver, gold, and platina: the other metals are calcined in those circumstances, and are called imperfect. It will easily be understood that these differences merely indicate different degrees of attraction for oxygen; and as in this respect, as well as in regard to malleability, there are numerous gradations among the metals, it will be necessary to treat separately of each metal as a distinct substance. I shall begin with such metals as have most resemblance to the earths, and are therefore called semi-metals, and conclude with those which have the metallic properties in the highest perfection.

Those metallic bodies with which we are at present acquainted, and which we can reduce to the metallic or reguline state, are the following seventeen;

* The name *regulus* was given by the fanciful alchemists to the metallic button, found in the bottom of the crucible after an assay, from the idea that this button contained gold, which they called the *king* of metals.

| | | | |
|---|---|---|---|
| 1. Arſenic. | Semi-metals. | 10. Iron. | Imperfect Metals. |
| 2. Molybdena. | | 11. Tin. | |
| 3. Tungſtein. | | 12. Lead. | |
| 4. Mangaueſe. | | 13. Copper | |
| 5. Nickel. | | 14. Mercury. | |
| 6. Cobalt. | | 15. Silver. | Perf. Met. |
| 7. Biſmuth. | | 16. Gold. | |
| 8. Antimony. | | 17. Platina. | |
| 9. Zinc. | | | |

Of theſe the nine firſt are called ſemi-metals, from defect of malleability; the five following imperfect metals, from their being calcineable by heat and air; and the three laſt, perfect, from their capacity of reſiſting the action of heat and air without change.

Metals exiſt in a ſtate of nature in four different forms.

1. They are found in a native ſtate of purity, with all the metallic properties. Gold is always found in this ſtate; ſilver, copper, mercury, biſmuth, and arſenic often; iron ſeldom; and lead, zinc, and regulus of antimony ſtill more rarely.

2. Metals are found in the ſtate of earth or calx, without the metallic aſpect, and often reſembling ochres.

3. The common ſtate, however, in which metals are found is that of ores. In this ſtate they are either combined with ſulphur or with ſome metal, the moſt common of which is arſenic *.

4. The laſt ſtate in which metals are found, is that of a combination with ſaline ſubſtances, and al-

* In this and the following ſtate they are ſaid, in technical language, to be *mineralized*; that is combined with ſome other mineral ſubſtance.

moſt always acids. The vitriolic acid is moſt frequently found combined with metals, viz. zinc, lead, copper, and iron. The carbonic acid is alſo a common mineralizer, and the arſenical and phoſphoric acids have likewiſe been diſcovered in combination with metals.

Metallic ſubſtances are more commonly found in mountains than in plains, and almoſt always in ſuch mountains as form continued chains. It is in the ſtratified mountains that metals moſt abound, where the inclination of the ſtrata, in conſequence of the convulſions of nature, brings a variety of ſubſtances into view, which muſt otherwiſe have been for ever concealed beneath the reach of human inveſtigation. There are entire mountains which conſiſt of iron ore, but in general the metallic part of a mountain is very inconſiderable in proportion to the whole. The ores ſometimes run parallel to the ſtony ſtrata; the layer on which the ore is placed is called the bed or floor of the mine; the other which covers it, is called the roof. Sometimes, however, the metallic ſtrata, which are always more irregular than the other ſtrata of which the mountain is compoſed, interſect the bodies which ſurround them in a variety of directions. The metallic ores are accompanied with ſtony matters, which ſeem to have been formed at the ſame time. Theſe ſtones are uſually quartz and ſpar; they are called the rider or matrix * of the metal, and muſt neither be confounded with the mineralizing ſubſtance which is

* So called from its frequently incloſing the ore. The ſparry matters are alſo ſometimes called by mineralogiſts *gangues*.

intimately combined with the metal, nor with the general mass of stone, of which the mountain containing the metal is composed. It is observed that the vegetables which grow on metalliferous mountains are dry, the trees small, sinuous, and deformed, and the sands often exhibit metallic colours. Mineral metallic springs are usually found in the vicinity; by the examination of which, and of the sands over which they flow, a tolerably accurate judgment may be formed of the metallic contents of the neighbouring strata. When metallic veins appear at the surface of the earth, the ground may be broken into with great probability of advantage, and the boring instrument, by bringing up the substances which compose the internal parts of the mountain, together with the metallic minerals, serves to shew their quality, as well as the resistance which may be expected in digging.

Before a metallic vein is wrought with a view to profit, it is necessary to ascertain the proportion of metal contained in it, and this is called assaying. In these small trials the fusibility of the mass is increased by the addition of three times the quantity of the black flux, which is made by burning together two parts of tartar with one of nitre. The alkali of this compound increases the fusibility of the stony matter mixed with the ore, and consequently affords the metal an opportunity of separating from it; while the charcoal contained in it, and which proceeds from the impurity of the tartar, abstracts the oxygen of the ore, and reduces the metal to a reguline form.

When

When the operation has been properly performed, the metal, or regulus, is found in the form of a button at the bottom of the mass, and being weighed shews the proportion of metal contained in the ore.

This method is used in reducing small quantities, as in assaying of ores, but would be too expensive in large operations. They then mix the ores or calces with the fuel, but let as little air as possible pass through it, as this would tend to re-calcine the metal. To prevent this effect, a particular sort of furnace is employed, in which charcoal is chiefly used.

It frequently happens that the same minerals contain the perfect metals mixed with the imperfect; these are separated both in the small and large way by heating the mixed mass in contact with air. By this operation the imperfect metal is reduced to a calx, and leaves the perfect metal in a state of purity. If the remaining metallic matter is still a compound, and contains two of the perfect metals, these are separated by exposing them, with as large a surface as possible, to the action of a menstruum, which has the property of dissolving one of them without the other.

There is also a method of assaying in the humid way, by submitting the ores to the action of different acids; but this is not so practicable as the other.

In the extraction of metals in the large way, the ore is pounded, washed, roasted, smelted, and refined. By pounding, the stony matters are separated from the metallic, and the whole being then washed on inclined planes or tables, the stony matter being lighter is washed away, while the metallic remains

 behind.

behind. The roasting or burning is intended to expel the volatile matters. Ores which contain much sulphur must be roasted in the open air, but such as contain but little may be roasted in the furnaces which afterwards serve to fuse them. Some ores are fusible alone, others require to be mixed with different fluxes. The methods of refining metals are extremely various, and depend on particular chemical affinities, which will be mentioned under the head of each metal.

The salts, and of them the acids in particular, have great effect on metals. Metals unite with acids into compounds, many of which crystallize. The corrosiveness of the acid is abated by its union with the metal, but not in so great a degree as by its union with the alkalies or earths. Neither is the point of saturation so well marked in the union of an acid with a metal as with an alkali. The same acid may, in many cases, be united to the same metal in different proportions; when the acid is in excess the mass is deliquescent, when it is deficent it seems to produce little other effect on the metal than to destroy its texture, and reduce it to a friable and earthlike state.

Every metal, however, is not disposed to unite with every acid, though some unite with all; others with only one acid. The order also in which the acids attract the metals is different from that in which they attract the alkalis. Metals attract the muriatic acid most strongly, next the vitriolic, and last the nitrous. Metals which dissolve in the same acid differ very much in the force with which

they

they adhere to it, so that they may be employed to precipitate one another. Thus, if we add to the solution of silver in aqua-fortis, quicksilver, it precipitates the silver; copper, the quicksilver; iron or lead, the copper; and zinc, which precipitates these, may itself be precipitated by an alkali.

The solution of metals in the acids is attended with the escape of an elastic vapour, and an effervescence. This was formerly adduced among the proofs for the existence of phlogiston, which, united with a small quantity of the water or acid, was supposed to constitute this elastic fluid, at the same time that the metal, by its loss, was deprived of its splendour, &c. This appearance is now proved to arise from a decomposition either of the acid or the water, and the elastic fluid differs in different cases, according to the source from which it derives its origin; when it arises from the decomposition of water, it is hydrogen or inflammable gas, when from that of the nitrous acid, nitrous gas, &c. Before the metal can be dissolved, it is necessary that it should be oxygenated; and therefore when its attraction is sufficiently strong, it decomposes the acid or the water, by abstracting their oxygen. It has been already remarked, that the muriatic acid has the strongest attraction for metals, and the nitrous less than either that or the vitriolic. From merely observing the action of these acids on metals, however, a different conclusion might be drawn, for the nitrous acid acts with violence and rapidity in comparison with the other two; and the muriatic,

 when

when in its purest state, has the least action of the three. This seeming inconsistency depends on the different degrees of attraction which the bases of the different acids have for oxygen. The reason, therefore, why some metals cannot be dissolved in particular acids, is, that they have not a sufficiently strong attraction for oxygen to decompose the acid. If we separate a metal from an acid by any substance which is not capable of depriving it of oxygen, we always obtain it in a calcined state. Thus gold, if precipitated from its solution in aqua regia by an alkali, is a calx; but if precipitated by any of the inflammable substances, as aromatic oils or spirits of wine, or by another metal, it appears in the metallic form. If metals are calcined previous to being united with acids, they produce no escape of gas, because being already furnished with oxygen, they have no tendency to decompose the acid.

Light appears to alter the colour and brilliancy of some metallic matters, independently of the action of air; for when exposed to light in transparent vessels well closed, they become tarnished, and lose their metallic brilliancy.

Heat applied to metals produces no other effects than expansion and fusion, if the air is completely excluded, unless carried to such a degree as to volatilize them; but even in that case, when the heat ceases to act, they return to their original state. Metals, on being converted into vapour, boil like other fluids, and even gold and silver are capable of this state when acted on by a large concave mirror.

Most

Moſt of the combuſtible bodies act on metals. Inflammable gas gives them a deeper colour, and is capable of reducing ſome of them to the metallic ſtate. Sulphur, and its combinations with alkalies, called hepars, act powerfully on metals.

From what is hitherto known of metals, there is every reaſon to believe that they are ſimple ſubſtances.

## CHAP. XVIII.

### ARSENIC.

*Natural History of Arsenic.—Mode of reducing it to the metallic Form.—White Enamel.—Orpiment.—Realgar.—Its Use in Medicine.—A dreadful Poison; how to detect it in the Body.—A Remedy for the Poison of Arsenic.*

ARSENIC is often found native, in black heavy masses, but not very brilliant. It has sometimes the metallic lustre, and reflects the colours of the rainbow; in its fracture it is more brilliant than at its surface, and seems composed of a great number of small scales. Native arsenic is very easily known, when it has the metallic brilliancy and scaly texture. Arsenic, however, is more frequently found in the form of flowers, or mixed with certain earths. Cobalt ores contain much arsenic, and that which is commonly sold is brought chiefly from the cobalt-works in Saxony. The ore is thrown into a furnace, resembling a baker's oven, with a flue or horizontal chimney, nearly two hundred yards long, into which the fumes pass, and are condensed in the form of a grey or blackish powder. This is refined by a second sublimation in close vessels, with a little pot-ash to detain the impurities. As the heat is considerable, it melts the flowers into those white crystalline masses which are met with in commerce.

The

The regulus is obtained from this substance, which is a calx of arsenic, by heating it with one-tenth of its weight of charcoal, or of any unctuous matter. The mixture is put into a tall vessel, and a gradual and gentle heat applied to the lower part of it, while the upper is kept cool by the air. The arsenic, when nearly red hot, parts with its oxygen, and rises to the upper part of the vessel, where it is condensed in the metallic form. To give it, however, its perfect metallic splendour and opacity, the sublimation must be repeated.

The regulus of arsenic is of a bright yellowish white colour, very ponderous and friable, and subject to tarnish and become black on exposure to air. If heat is applied to the regulus in contact with air, it is volatilized before it melts, and is at the same time imperfectly calcined. The fumes are dangerous, and have a strong and offensive smell, resembling that of garlic.

The white calx of arsenic is so far in a saline state as to be soluble in eighty times its weight of cold, or fifteen times that of boiling water. When distilled with the nitrous acid, it decomposes that fluid by depriving it of part of its oxygen. The arsenic, by this addition of oxygen, is reduced to the state of an acid less volatile than either the regulus or calx, but retaining the form of a white concrete substance. The oxygenated muriatic gas likewise reduces arsenic to the state of an acid.

Arsenic readily melts with other substances so as to form glass, and even promotes their fusion. At first it always renders the glass milky, but by a continuation

tinuation of heat the arsenic evaporates, and the glass becomes quite transparent. It is an ingredient in the white enamel dial-plates; and it forms those white spirals which are common in the stalks of wine-glasses.

Sulphur unites readily with arsenic into a compound more fusible than the arsenic itself. Orpiment is a combination of arsenic and sulphur, of a yellow colour. It is found naturally in the earth, generally of an irregular form, and composed of shining flexible laminæ. Its specific gravity, according to Kirwan, is 5,315, who also asserts that it contains one-tenth part of its weight of sulphur. The same author mentions, that realgar, or the red combination of arsenic and sulphur, contains sixteen parts of sulphur in the hundred, and is of the specific gravity of 3,225. Chaptal, however, observes that the difference between realgar and orpiment does not consist in the proportions of sulphur, nothing more being necessary in order to convert orpiment into realgar, than exposure to a strong heat. The violent action of arsenic on the animal machine is much abated by combination with sulphur. Common white arsenic has sometimes been successfully used in doses of one-twelfth or one-sixteenth of a grain. Received, however, in any considerable quantity into the body, it produces dryness of the mouth, heat in the throat, excruciating pains in the bowels, attended sometimes with vomiting of blood, cold sweats, &c. On dissection, the bowels are found inflated and corroded. Many black and livid spots appear on the stomach and small intestines,

tines, sometimes gangrenous. But these signs are not altogether to be depended on. Some of the arsenic is frequently found, and may be easily distinguished. The powder is heavy, and easily seperates from the lighter contents of the bowels, by washing with water; the arsenic always falling to the bottom. A very little of this is sufficient to give the smell of garlic, and tinge copper white, if heat is applied to it.

It was formerly usual to give mucilaginous drinks, or milk or mild oils, to persons poisoned by arsenic. But Navier, a physician of Chalons, who has made experiments to ascertain the best remedies against the poison of arsenic, has discovered a substance which combines with it in the humid way, and destroys, in a great measure, its causticity. This substance is the calcareous or alkaline liver of sulphur, and is still better adapted to the intention, when it holds a small quantity of iron in solution. When this martial hepar is poured into a solution of arsenic, it is decomposed without emitting any smell, because the arsenic combines with the sulphur, and forms orpiment, and at the same time unites with the iron. Navier prescribes a dram of the liver of sulphur in a pint of water, of which he directs a glass to be taken at a time; or five or six grains of dry liver of sulphur may be given in pills, a glass of warm water being given after each pill. When the first symptoms are dissipated, he recommends the sulphureous mineral springs. Navier likewise approves the use of milk, because it dissolves the arsenic as well as water, but he condemns

demns the uſe of oils, which have not that property.

Arſenic ſhews a ſtrong diſpoſition to unite with all the metals except platina. By a mixture of it in its ordinary ſtate with copper, a metal is produced reſembling ſilver. It generally gives metals a white colour, and renders them brittle.

## CHAP. XIX.

### MOLYBDENA.

*Short Account of this Semi-metal.—May be reduced to an Acid.—A scarce Mineral.*

THIS is a mineral ſubſtance, which has till lately been confounded with plumbago; but is now found to be a combination of a particular metallic ſubſtance with ſulphur. It is of a blackiſh colour, and conſiſts of ſhining laminæ, which have a degree of flexibility, ſo as to be very difficultly reduced to powder.

Molybdena reduced to its metallic form reſembles lead in colour and ſpecific gravity, but is very brittle, eaſily calcined and volatilized, and will not mix with lead when in fuſion.

Molybdena is capable of being oxygenated ſo far as to become an acid, in which ſtate it is a concrete body, white and pulverulent, reſembling chalk. This acid, heated with ſulphur in a particular manner, is capable of being converted into a ſubſtance in every reſpect the ſame as native molybdena.

This mineral is ſcarce. It is diſtinguiſhed from black lead by a more ſhining, ſcaly appearance; and it marks paper with a more brilliant ſtroke.

## Chap. XX.

### TUNGSTEIN.

*The Ore of Tungstein confounded with that of Tin.—Where found.—Mode of reducing it to the reguline or metallic State.*

TUNGSTEIN or wolfram is a particular metal, the ore of which has frequently been confounded with that of tin. The ſpecific gravity of this ore is to water as ſix to one; in its form of cryſtallization it reſembles the garnet, and varies in colour, from a pearl white to yellow and reddiſh; it is found in ſeveral parts of Saxony and Bohemia. The mineral called wolfram, which is frequent in the mines of Cornwal, is likewiſe an ore of this metal; in all theſe ores the metal is oxydated; and in ſome of them it appears to be oxygenated to the ſtate of an acid, being combined with lime into a true tungſtat of lime *.

The calx of this metal cannot be obtained free from the bodies with which it is united, without a particular proceſs, which conſiſts in the alternate application of volatile alkali and marine acid, and the ſubſequent addition of the nitrous acid, as long as red fumes are produced. This calx or imperfect acid has the colour of brimſtone, and is ſcarcely ſoluble in water. By being ſubmitted in a crucible

* Lavoiſier's Chemiſtry.

with

with charcoal, to a ſtrong heat, a regulus of tungſtein may be obtained, which is a brown maſs, conſiſting of a congeries of metallic globules; and again becomes yellow by calcination. The regulus is not acted on by the vitriolic and marine acids; the nitrous acid, however, and aqua regia, act on it, and by oxygenating it reduce it to its calciform ſtate.

M. Lavoiſier recommends the following proceſs for obtaining the calx of tungſtein: Mix one part of ore of tungſtein with four parts of mild vegetable alkali, and melt the mixture in a crucible, which ought to be of platina; then powder, and pour on twelve parts of boiling water; add pale nitrous acid, and the tungſtenic acid precipitates in a concrete form. Afterwards, to inſure the complete oxygenation of the metal, add more pale nitrous acid, and evaporate to dryneſs, repeating this operation as long as red fumes are produced from the acid.

## Chap. XXI.

### MANGANESE.

*Natural History of Manganese.—Its Effects on Glass.—Regulus or Metal.—Black Wad.—Manganese contained in Vegetables.—Uses in the Arts.*

THIS metal is almost always found in the state of calces, which vary much in colour and appearance; they are white, blue, yellow, red, dark green, and black, according as they are united with more or less oxygen, or contaminated with foreign substances. The darker coloured the ores, the more oxygen they may be supposed to contain, as any process which deprives them of this principle always renders them paler. Manganese is also found crystallized in a variety of forms. Many naturalists, judging by their colour, and the ochry * crust with which they are often surrounded, have ranked the calces of manganese among the iron ores. The black calx of manganese gives a violet, purplish, and sometimes a reddish tinge to transparent glass; but when added in a small quantity to that which has a blueish or greenish cast, it produces only a slight duskiness, without a predominancy of any colour.

The regulus of manganese is very difficultly obtained. Its colour is a dusky white, but its masses are irregular and uneven from imperfect fusion. Its fracture is bright and shining, but it soon tar-

* Ochre being an iron ore.

nishes

nishes and becomes blackish on exposure to air. When pulverized it is always magnetic, though it has not this property in the mass. If exposed to air, particularly in moist weather, it soon crumbles into a blackish brown powder, which is somewhat heavier than the regulus from which it was produced.

The calces of manganese retain their oxygen so weakly, that part of it may be expelled by the application of a strong heat. They also part with their oxygen to unctuous oils. If half a pound of that ore of magnanese called black wad is well dried before the fire, afterwards suffered to cool for about an hour, and then mixed with two ounces of linseed-oil, small clots will be formed, and in little more than half an hour the whole will gradually grow hot, and at last burst into flame.

Manganese seems to be contained in the ashes of most vegetables, and to it the blue or greenish colour of calcined vegetable alkali is owing. If three parts of alkali of tartar, one of sifted ashes, and one-third of nitre, are melted together, they form a dark green mass, which being dissolved in water, affords a beautiful green solution; this being filtered, on the addition of a few drops of vitriolic acid becomes red, and after a few days a brown powder is separated, which has all the properties of manganese.

The vitriolic, nitrous, and marine acids dissolve the regulus of manganese in the usual ways. The black calx is nearly insoluble in the acids, unless it is deprived of part of its oxygen by the addition of some inflammable or metallic substance. The

marine acid, however, digeſted with the black calx of manganeſe, diſſolves it without addition, in proportion as it loſes ſome part of its oxygen. The oxygen uniting with part of the muriatic acid, renders it volatile, and converts it into oxygenated muriatic acid. The permanent ſolubility of the black calx of manganeſe in the acids, depends on the acid, or ſome ſubſtance mixed with the acid, abſtracting part of its oxygen. The manganeſe ſeparated from its ſolution in acids by alkalies, is in the form of the white or imperfect calx, which, however, becomes black by being heated in contact with air.

In the dry way the calx of manganeſe combines with ſuch earths and ſaline ſubſtances as are capable of undergoing fuſion in a ſtrong heat. The violet colour which it communicates to glaſs is liable to be deſtroyed by combuſtible ſubſtances. From this circumſtance we may conclude, that the property of colouring glaſs depends on the calciform ſtate of this metal, and that it is loſt when any body abſtracts its oxygen and reduces it to a regulus.

Manganeſe in its metallic form will not unite with ſulphur, but melts readily with moſt of the metals. Gold and iron are rendered more fuſible by a due addition of manganeſe, and the latter metal is rendered more ductile.

Manganeſe has hitherto been uſed chiefly by glaſs-makers and potters; but the important diſcoveries of the effect of oxygenated muriatic acid, prepared by means of manganeſe, in bleaching, will no doubt extend its utility to ſeveral other manufactories.

CHAP.

# CHAP. XXII.

## NICKEL.

*Natural Hiſtory of Nickel.—Metal how obtained.—Detonates with Nitre.—Has a ſtrong Repulſion for Silver, and Attraction for Sulphur.—A uſeleſs Mineral.*

THIS metal derives its name from the mineral in which it is contained. It is found united with ſulphur and arſenic. Its ores have a coppery red colour, are almoſt always covered with a greeniſh grey efflorefcence, and have been miſtaken for ores of copper. The ores of nickel often contain cobalt and iron. Moſt of the ſulphur and arſenic may be driven off by long continued roaſting, and the occaſional addition of charcoal, which prevents the arſenic from being rendered more fixed by calcination; and the green calx which remains may be fuſed by the ſtrongeſt heat of a ſmith's forge, together with two or three times its weight of black flux. By theſe means a regulus may be obtained, which, however, is very far from being pure, as it contains much arſenic, cobalt, and iron. In this ſtate it is of a white colour with a tinge of red, and has a granulated texture. When this metal is rendered more pure by treatment with ſulphur, charcoal, volatile alkali, and nitre, it becomes extremely infuſible, loſes ſomewhat of its reddiſh tinge, and acquires a conſiderable degree of malleability. Nickel may be freed from ſulphur and arſenic, but

it cannot be accurately purified from cobalt and iron, for it is considerably attracted by the magnet; and gives signs of containing cobalt, after the utmost pains have been taken to obtain it in a pure state. It affords a blue solution with volatile alkali, and in nitrous acid its solution is of a full green.

From its magnetic property, nickel has been considered as a modification of iron; and by its producing a blue colour with volatile alkali, it has been supposed to be an alloy of copper with various metallic substances. Chemists, however, are now very generally agreed in considering nickel as a distinct metallic substance.

M. Sage affirms, that when four parts of oil of vitriol are distilled with one part of the regulus of nickel in powder, the sulphureous acid passes over; the residue is greyish, and, being dissolved in distilled water, produces the most beautiful green colour. The crystals obtained from this solution are foliated, and of the colour of an emerald. According to M. Arvidson, the vitriolic acid forms a green salt, in decahedral crystals, with the calx of nickel.

This calx is easily soluble in the nitrous acid, and crystallizes in rhombic cubes. According to M. Sage, all the other solutions of nickel, or its calx, either in the muriatic acid or in vegetable acids, are more or less green. It has been said, that the nickel contained in cobalt occasions the substance known under that name to produce a green colour with acids. Nickel differs from

cobalt in not being separated from acids by the addition of any other metal.

Nickel detonates * with nitre; this detonaticn afforded Mr, Arvidson a method of discovering the presence of cobalt, which no other proof has rendered sensible. Nitre has likewise the property of augmenting the intensity of the hyacinthine colour, communicated to glass by the calx of nickel. The calx of nickel, fused with borax, likewise produces a hyacinthine colour. The calces of nickel are of a green colour.

The most remarkable properties of the regulus of nickel are, a repulsion for silver, and a strong attraction for sulphur. It has so strong an affinity for sulphur, as to attract it from most other metals.

Nickel combines by fusion with sulphur into a hard mineral of a yellow colour, with small brilliant plates, which, when strongly heated in contact with air, deflagrates and emits very luminous sparks, similar to those afforded by iron when forged. Cronstedt informs us that this metal is soluble in liver of sulphur, and forms a compound resembling the ores of copper. The sulphur can only be separated from nickel by repeated fusions and calcinations.

Cronstedt affirms that nickel forms, with bismuth, a brittle and scaly regulus. Nickel has not yet been applied to any use.

* Inflames, and explodes suddenly.

## CHAP. XXIII.

### COBALT.

*Natural Hiſtory of Cobalt.—Analogy between this Metal and the blue colouring Matter of Vegetables.—Mode of aſſaying it.—Mines of Cobalt.—Smalt, or Powder Blue.—Uſes of Cobalt in the Arts.—Curious ſympathetic Ink.—Changeable Landſcape.—Union with other Metals.*

COBALT has never been found native, that is in a metallic ſtate, but is almoſt always calcined or united with arſenic, the arſenical acid, ſulphur, iron, vitriolic acid, &c. Minerals containing cobalt are frequently of a pink colour, which ariſes from the preſence of arſenical acid, and its colour is deſtroyed by fire, in proportion as the acid is diſſipated. When united with vitriolic acid, it alſo is ſometimes reddiſh: the effect of acids on cobalt points out an analogy between it and the blue colouring matter of vegetables.

To aſſay cobalt ores, the operations of pounding, waſhing, and roaſting muſt be all employed. The cobalt remains in a ſtate of black calx, more or leſs deep with reſpect to colour; this is mixed with black flux and a ſmall quantity of decrepitated ſea ſalt; the fuſion is performed in a forge heat in a covered crucible, which muſt be ſlightly agitated, to precipitate the metal as ſoon as the fuſion is complete. The metallic button is ſometimes found to conſiſt of two diſtinct ſubſtances, cobalt being

uppermoſt, and biſmuth beneath; a ſtroke of the hammer readily ſeparates them.

The regulus of cobalt is of a whitiſh grey or ſteel colour, hard, brittle, of a dull cloſe-grained fracture, and moderate ſpecific gravity. It has about the ſame degree of fuſibility as copper; does not eaſily become calcined; and its calx is of ſo deep a blue colour as to appear black. Cobalt expoſed to heat does not melt till it is well ignited. It appears to be very fixed in the fire, and it is not known whether it can be volatilized in cloſe veſſels. If it is ſuffered to cool ſlowly, it cryſtallizes in needle-formed priſms, placed one on another, and united in bundles. Cobalt, melted and expoſed to the air, becomes covered with a dull pellicle, which is a calcination analogous to the ruſting of iron.

The richeſt mines of cobalt are in Saxony. The ore which is worked there in the large way contains a conſiderable quantity of arſenic, which is driven off by heat, but is collected in long channels of wood, and preſerved for ſale, as was intimated before. After the ore has been kept ſome time in the furnace, there remains a dark friable ſubſtance, which is the cobalt in the form of a calx, and called *zaffre*. This is mixed with the ordinary ingredients of glaſs, and melted with a violent heat, ſo as to produce the common blue powder called ſmalt, which is a pounded glaſs. Some of this is mixed with flints and alkaline ſalts, and then ſold under the name of ſapphire to the manufacturers of porcelain and common Delft ware, for tinging their glazing blue.

Powder

Powder blue, or azure, is obtained by grinding ſmalt in mills, and afterwards waſhing it in water. This laſt operation is performed in a caſk filled with water, and pierced with three openings at different heights. The water of the uppermoſt cock carries out the fineſt blue. The larger particles fall more ſpeedily, and the azure brought out by the water of the three cocks forms the different degrees of fineneſs, known by the names of azure of the firſt, ſecond, and third fires. Powder and ſtone blue, uſed by laundreſſes, is a preparation made by the Dutch from the coarſe ſmalt.

A ſmall quantity of the calx of cobalt tinges glaſs of different ſhades, according to the quantity uſed. One grain of cobalt to ſeven thouſand of the glaſs, renders it very blue: hence the paſtes in imitation of ſapphire are produced. Stained flint glaſs is made by ſixteen parts of ſand, eight or ten of pearl aſh, and metals in different proportions.

Cobalt diſſolves readily in aqua-fortis, both in its metallic ſtate and in that of a calx. If we take a ſolution of its calx in that fluid, and add a quantity of water to it, and then let it ſtand a while, it turns red, and on evaporation forms cryſtals of the ſame colour, and by this it may be diſtinguiſhed from all other metals. This ſolution forms a red ſympathetic ink, which appears on the paper by heat, and again diſappears by cold.

Aqua-regia diſſolves cobalt more eaſily than the muriatic, but not ſo eaſily as the nitrous, acid. This ſolution is a celebrated ſympathetic ink. If it is diluted with a ſufficient quantity of water to pre-

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vent its action on paper, and then used to write with, the letters are invisible as soon as the clear solution becomes dry; but if the paper is held to the fire for a short time, they appear of a fine green colour; which again disappears by removing it, and suffering it to cool. If held to the fire too long, the green colour becomes permanent. From these two inks a very curious changeable landscape may be made. The trunks of trees, houses, &c. may be painted with common colours, so as to represent winter. The verdure, the fruits, and the flowers may be depicted in different shades of the two inks. On aproaching the fire the landscape will gradually be changed from a winter to a summer scene. The trees will begin to shoot out their foliage, and the flowers and the fruits will, by degrees, assume the appearance of maturity. The vivid parts will again fade, on being removed from the heat, and the landscape resume the wintry aspect.

It was formerly thought that the green colour produced by heat in the sympathetic ink of cobalt, arose from the metallic salt being crystallized, and afterwards attracting a sufficient quantity of water from the cold air to dissolve it, and cause it to disappear; but it is proved, that the marine salt of cobalt, dissolved in water, assumes the same colour when exposed to a certain degree of heat.

The vitriolic acid in a concentrated state does not dissolve cobalt without the assistance of heat, when the acid is decomposed, and comes over in sulphureous fumes. The cobalt is in part calcined, and in part converted into a crystalline salt soluble in water,

and which may be precipitated by lime and by alkalies, in the form of a rose-coloured powder or calx. Diluted vitriolic acid acts upon the calx of cobalt, and forms the same salt.

Cobalt unites with all the metals except silver, lead, quicksilver, and bismuth, but does not produce any remarkable or useful compound with any. It is separated from acids by zinc in the form of a dark-coloured powder, but not by iron.

A mixture of nickel with the calx of cobalt very much injures the colour which the latter communicates to glass. The following process is one of the best for separating them when the cobalt is in considerable quantity: Saturate a solution of the roasted ore in nitrous acid, and drop it into liquid volatile alkali. The cobalt then is instantly re-dissolved, and assumes a garnet colour; when filtered a grey powder remains on the filter, which is the nickel. The cobalt may be precipitated by any acid.

# CHAP. XXIV.

## BISMUTH.

*External Qualities of Bismuth.—A powerful Dissolver of Earths.—Pearl White, a pernicious Cosmetic.—Curious Experiment.—A metallic Composition, which melts in boiling Water.—Various Uses of Bismuth in the Arts.*

BISMUTH is extremely brittle, so that it may be easily separated, and even reduced to powder by the hammer. When broken it exhibits at the place of fracture large shining plates, disposed in a variety of directions. It is considerably ponderous, and is of a yellowish white colour; when in thin plates it is in some degree sonorous. It is very fusible, and melts at a temperature not exceeding 460° of Farenheit.

Bismuth is scarcely altered by exposure to air and light. In closed vessels it sublimes without alteration; it crystallizes the most easily of any metallic substance. If bismuth is kept in fusion in contact with air, its surface becomes covered with a pellicle, which changes into an earth of a greenish grey or brown, named calx of bismuth. Nineteen drachms of bismuth, calcined in a capsule of glass, afforded M. Baumè twenty drachms thirty-four grains of calx. Bismuth heated to redness burns with a small blue flame, scarcely sensible. Its calx evaporates in the form of a yellowish smoke, which condenses on the surface of cold bodies, into a powder of the

the ſame colour, called flowers of biſmuth. This powder owes its volatilization only to the rapidity with which the biſmuth burns; for if it is expoſed in cloſe veſſels to fire, it melts into a greeniſh glaſs without ſubliming. Geoffroy the younger obſerved, that the flowers of biſmuth, which riſe the laſt, are of a beautiful yellow, reſembling orpiment.

The grey or brown calx, the yellow flowers, and the glaſs, are nothing more than combinations of this metal with the baſe of vital air, which are not reducible without addition.

Calx of biſmuth is one of the moſt powerful diſſolvers or liquefiers of earthy bodies, or of the calces of other metals, and gives a yellowiſh tinge to glaſſes, into the compoſition of which it enters. Biſmuth is alſo readily calcined by nitre, but without detonation. The alkalies have little effect on biſmuth; when applied, however, in a cauſtic ſtate, they diſſolve part of the metal.

The vitriolic and muriatic acids do not act on biſmuth, unleſs aſſiſted by heat. The nitrous acid, however, diſſolves it with great rapidity, and during the ſolution copiouſly emits denſe red vapours. This is one of thoſe ſolutions from which the calx is moſt eaſily ſeparated by water. On being dropped into water a bright powder is depoſited, called magiſtery of biſmuth. This is ſuppoſed to be the ſame with the ſubſtance called *pearl white*, well known as a coſmetic; for when rubbed on the ſkin it gives it a white ſhining colour. But in reality all theſe metallic ſubſtances ultimately darken the ſkin, for a calx when long

expoſed

expoſed to the air, and the exhalations of animal bodies, parts with its oxygen to the inflammable matter, and aſſumes a dark colour. Biſmuth, moreover, poſſeſſes many properties in common with lead, and there are ſome inſtances in which the external uſe of this metal has produced the worſt effects.

Solutions of biſmuth are particularly affected by fetid odours, which proceed from putrefying ſubſtances. This ſeems chiefly to depend on the ſulphureous particles which are exhaled in thoſe proceſſes, and is illuſtrated by a ſtriking experiment. If characters are written with a ſolution of biſmuth on the firſt page of a book of fifty leaves, and the laſt page is impregnated with a ſmall quantity of the liquid liver of ſulphur, a ſhort time afterwards the hepatic vapour, carried by the air which circulates between all the leaves, arrives at the other extremity of the book, and converts the colourleſs characters marked on the firſt page into a deep brown. It is affirmed that the hepatic gas paſſes through the paper; but it is ſufficiently proved that the air carries the gas in this manner from one leaf to another, ſince the effect does not take place when the leaves are glued together. This experiment evinces in the cleareſt manner the impermanency of the beautifying effect of the calces of biſmuth.

The nitrous ſolution of biſmuth is without colour, and when well ſaturated affords cryſtals without evaporation. But by evaporation and cooling theſe cryſtals may always be obtained. The nitre of biſmuth detonates feebly, and with reddiſh ſcintillations;

tions; after which it melts and inflates, leaving a calx of a greenish yellow colour. This salt exposed to the air loses its transparency, at the same time that the water of crystallization is dissipated.

The acetous acid dissolves bismuth slowly, and in small quantities.

Inflammable gas alters the colour of bismuth, and gives it a violet tinge. Sulphur unites with bismuth, especially with its calx; in which state it resembles crude antimony. It unites with all the metals, except zinc and regulus of cobalt, and takes away their malleability and ductility, and increases their disposition to calcine; it also increases their fusibility, hence its use in soldering lead and tin. If added to a mixture of lead and tin, in certain proportions, it produces a metallic compound, which retains the state of fluidity in the heat of boiling water.

Bismuth is chiefly useful for mixing with tin to produce pewter, rendering it harder, and better to be cast into molds. It is also used in making printers' types; for by giving a greater tenuity to the fused mass, it fits it for receiving a neater impression. An amalgam for foiling glass globules is made of ten parts of mercury, two of bismuth, and one of lead and tin. It may be substituted instead of lead in the art of cupelling the perfect metals, because, like that metal, it has the property of flowing into a glass which is absorbed by the cupels.

Bismuth

Bismuth is often found native. It is also found united with arsenic, sulphur, iron, and sometimes in a calciform state. The sulphureous ore of bismuth is of a whitish grey, inclining to blue; it has the brilliancy and colour of lead ore or galena, and almost always exhibits square facets, but it is never found in fragments truly cubical. It is very rare, and is found at Bastnas, in Sweden, and at Schneeburg, in Saxony.

## CHAP. XXV.

### ANTIMONY.

*Natural History of Antimony.—Regulus.—Snow of Antimony.—Calcination of Antimony.—Combinations with Acids.—Butter of Antimony.—Antimonial Wine.—Uses of Antimony in Medicine.—Flores Antimonii.—Glass of Antimony.—Crocus of Antimony. Sulphur of Antimony.—Tartar Emetic.—James's Powder.*

THE ſubſtance, which is commonly known by the name of antimony, is a combination of that metal with ſulphur. This mineral is of a blackiſh grey, in brittle plates or needles, of various magnitudes, joined together in different forms. It is ſometimes mixed with other metals, particularly lead and iron, and is very common in Hungary, and in ſome of the provinces of France. From this ore the regulus of antimony is ſeparated by fuſion. The antimony then forms a maſs of metal at the bottom of the veſſel, while the other matter becomes a ſcoria above it.

The appearance of antimony is bright, approaching, when very fine, to that of ſilver. It is very brittle, and it is compoſed of oblong plates or laminæ. When melted it forms a ſmooth maſs like other metals, but upon breaking it, we find the plated appearance on the inſide. The plated appearance depends on the cryſtallization, which begins at the part that firſt congeals. The regulus of antimony, which is prepared for commercial pur-

poses, is cast into flat and circular pieces, which have a crystallization on their surface, in the form of the leaves of fern.

In fusibility antimony holds a middle rank, requiring a perceptible degree of red heat before it becomes fluid. In the same degree it emits vapours copiously if fresh air is admitted, which always promotes the volatility of metals. If these fumes are condensed, they form a white powder. In particular circumstances they crystallize. They are, indeed, a perfect metallic calx, to which the names of argentine, and snow of antimony, have been applied. This substance is so highly charged with the oxygenous principle, as to be soluble in water, and to approach to the nature of an acid.

To calcine antimony by heat and air alone, let the metal be powdered, then lay it on a broad shallow vessel, and apply heat not sufficient to convert it into fumes. This operation cannot be well performed, unless the antimony is in a state of minute division, so as to present a large surface to the air. The process must be conducted with caution at the beginning, on account of the fusibility of this compound of sulphur and antimony; but in proportion as the sulphur is dissipated, the remainder becomes more refractory, and the fire may be raised to such a degree as to make the vessel in which the antimony is contained red hot. The surface of the metal becomes at first tarnished, and soon afterwards it is changed into an earthy powder of a dusky colour, which, by continuance of the process, becomes white. These calces have a different degree of

frisibility according to the degree of calcination. When little calcined a strong heat converts them into a glass of an opake or black colour. When further calcined more heat is required, and the glass is a deep yellow. When calcined to whiteness, the most violent heat will not melt them without the addition of borax, and the mass is then of a pale yellow. Here we observe the effect of the presence of oxygen in rendering this calx less fusible, and depriving it of colour. These calces may be reduced, but most readily when little calcined, by adding an equal quantity of black flux, or one-fourth of charcoal or soap.

The fossil fixed alkali brings antimony nearest to the state of the perfect metals. For this discovery we are indebted to Margraff, who melted two ounces of regulus of antimony with one of fossil alkali. He repeated the fusion eight times, and every time he used fresh alkali; but the three or four last times he did not use quite an ounce of alkali, but made use of a mixture of alkali and flint. Every time it was thus melted the regulus lost some of its weight, and the alkali, having dissolved part of it, was tinged green. The remaining metal was always whiter and brighter, and acquired a small degree of toughness. The texture was much finer than before, and it would easily amalgamise with mercury. The weight of the regulus was reduced to about one half by eight operations. With the vegetable fixed alkali the effect was similar, but not so remarkable.

The

The regulus of antimony is calcined with great rapidity by the nitrous acid, but the muriatic and vitriolic ſcarcely act on it, unleſs aſſiſted by heat. By the union of antimony with all theſe acids, ſaline compounds are produced, which are deliqueſcent, and which are decompoſed by water, or the ſimple application of heat. The oxygenated muriatic acid and aqua regia diſſolve the regulus of antimony with great facility.

But beſides theſe methods of aſſiſting the action of the muriatic acid on antimony, there is another proceſs for combining the muriatic acid with the regulus. A quantity of mercurial ſublimate in powder being mixed with the regulus of antimony, the acid acts upon the antimony immediately, ſo as to render the mixing of them dangerous, from the corroſive fumes which ariſe. The common way is to powder them and mix them, and heat being applied, the muriatic acid of the ſublimate attracts the antimony, and riſes with it in the form of a very volatile compound, which condenſes in the neck of the retort, of a conſiſtence between ſolid and fluid, and is hence called butter of antimony. It is very cauſtic, and is uſed to conſume the callous lips of ulcers, but is too violent to be uſed internally. If it is ſubjected to a ſecond operation, it comes over fluid. The ſame proceſs is employed to combine other metals with the muriatic acid. When butter of antimony is thrown into pure water, an abundant white precipitate or calx falls down, which is a violent emetic, and is known by the name of powder of algaroth.

The vegetable acids alſo act upon antimony weakly when applied to it in its metallic ſtate, but much more ſtrongly when it is ſlightly calcined. A ſolution of this kind was formerly uſed under the name of antimonial wine. A quantity of the regulus was caſt in the form of a cup, which was occaſionally filled with wine, and having ſtood a day or two, it became emetic. The quantity of antimony diſſolved was very ſmall, but was diſcoverable on adding an alkali, and precipitating it.

To give crude antimony any action as a medicine, it is neceſſary to deſtroy a part of the ſulphur, and alſo in ſome meaſure to calcine it. The more ſulphur it retains, the leſs active it is. If we calcine it too much we alſo deſtroy its effects; for in the ſtate of a white calx it has little or no medical efficacy. The flores antimonii is a preparation in which the antimony is nearly deprived of ſulphur, and at the ſame time furniſhed with ſome oxygen. It is very violent in its effects; a very minute quantity producing convulſions and vomiting. Antimony indeed may be reduced to ſuch a ſtate as to affect the body in ſmaller quantities even than arſenic.

When antimony is combined with ſulphur, and urged with a ſtrong heat, it aſſumes the appearance of glaſs. The glaſs of antimony, though not much employed as a medicine, is very uſeful as a preliminary to the moſt valuable preparations. Few of the metals, indeed, have ſo much attracted the attention of chemiſts as antimony, and its preparations have been accordingly very nume-

rous,

rous. To avoid, therefore, unneceffary prolixity, it will be proper to confine the reader's attention to thofe which have been found moft ufeful.

By deflagrating antimony with nitre, the metal is calcined, as well as when expofed to heat in contact with air. The antimonium calcinatum of the London Pharmacopœia is prepared by throwing a mixture of eight ounces of antimony, with two pounds of nitre, into a crucible heated to a white heat. The white matter is burnt for half an hour, and, when cold, is powdered and wafhed with diftilled water. This preparation is fo inert, that it has been doubted whether it is capable of any action whatever on the human body.

When the antimony and nitre are in equal quantities, they form a more active compofition. The mixture burns with violence, and ought to be injected, in fmall quantities at a time, into the heated crucible. After the combuftion there remains a mixed matter, partly of a dark red, and partly whitifh. Upon melting, it feparates into a heavier part of a deep red, and a faline part above of a paler colour. The former is the object of the operation, and is called crocus of antimony. The College direct a fmall quantity of fea falt to be ufed in this preparation, which promotes fufion, and probably increafes the activity of the compofition.

Fixed alkalies have a great degree of activity with crude antimony, on account of their attraction for the fulphur. The eafieft mode of combining them is fufion. The firft effect of the alkali is to combine with the fulphur, and form a liver of

ſulphur, which by a continuance of heat ſeems to diſſolve the regulus of antimony. This compound is readily diſſolved by boiling water, and if we add to the ſolution an acid, the metallic matter and ſulphur are depoſited of a yellow colour. This ſubſtance, however, which is called ſulphur antimonii præcipitatum, may be obtained in an eaſier manner, by boiling crude antimony in a ſolution of alkali, and then precipitating the ſulphurated antimony with the vitriolic acid.

The antimonium tartariſatum, or *tartar emetic*, may be obtained either by the uſe of the crocus or the glaſs of antimony. The former is, however, preferred by the London College, who adopt the following proceſs: Take of crocus of antimony powdered one pound and an half, cryſtals of tartar two pounds, diſtilled water two gallons. Boil them in a glaſs veſſel about a quarter of an hour; filter the liquor through paper, and ſet it by to cryſtallize. Tartar emetic conſiſts of the acid of tartar united to vegetable alkali and antimony partially calcined.

The pulvis antimonialis of the pharmacopœia, which is thought to be nearly the ſame as James's powders, is prepared by expoſing equal parts of antimony and hartſhorn ſhavings to a moderate heat, with a free acceſs of air. With reſpect to the peculiar merits of James's powders, they have never been proved either in theory or practice. The circumſtances upon which the effects of antimonial preparations depend are well known, and though we cannot with certainty aſcertain

the proceſs of Dr. James, there is no reaſon to think that it is preferable to that of the pharmacopœia, in the preparation of the pulvis antimonialis. The love of myſtery, however, has always had an influence over mankind, and there is no reaſon to believe that the period for its ceſſation is at hand.

The regulus of antimony is employed in the manufacture of printers types, and in making ſhot.

## CHAP. XXVI.

### ZINC.

*General Description of this Metal.—Philosopher's Wool.—Union with Acids.—White Vitriol.—Detonation of Zinc with Nitre.—Combination with Metals.—Pewter.—Its Use in Fire-works.—Natural History of Zinc.—Calamine.---Black Jack.----Brass, how made.---Tutty.---Pinchbeck.*

THIS metal is in ſome degree malleable, and therefore holds a middle place between the ſemi-metals and metals, though it is uſually referred to the former diviſion. Its appearance is blue and brilliant, and when broken it is found to be cryſtallized in narrow plates. It melts when red hot; if heated in cloſe veſſels to a vivid red or white heat, the whole of it riſes in vapour, and may again be condenſed without any change. When heated, however, in contact with air, it burns rapidly with a white flame and crackling noiſe, and is converted into a white, ſoft, and flocculent ſubſtance, called flowers of zinc, or lana philoſophorum. If the zinc is burnt in a deep crucible, this calx attaches itſelf to the upper part of it, though ſome part is always loſt even in the deepeſt veſſel, which will admit the air with ſufficient freedom to maintain the combuſtion. If a gentle heat is applied no light is produced, and the ſurface of the zinc becomes gradually covered by a grey calx, which changes to white, by being afterwards heated in con-

tact

tact with air. Zinc is so apt to undergo this change that it is difficult to melt small pieces of it into a mass, for in the moment after they arrive at the melting point they are covered with a skin, which prevents their union. The calx of zinc is not very easily reduced to a reguline state, as the heat necessary for this effect is apt to volatilize the metallic product.

Zinc is readily acted on by all the acids, and no metal shews a greater attraction for them. It produces with them metallic salts, in which the acid is more neutralized than in the other metallic compounds of the same description. The acids do not deposit the zinc when they are diluted with water.

The concentrated vitriolic acid does not act on zinc, unless assisted by heat, and it then gives out sulphureous fumes. It is dissolved, however, with rapidity, and without the assistance of heat, by the same acid in a diluted state, and this process is attended with the copious production of hydrogen gas, which indicates the decomposition of the water. From this solution may be obtained white vitriol, which, as well as the flowers of zinc, is employed in medicine.

The diluted nitrous acid acts on zinc with singular violence, and nitrous gas is so copiously disengaged, that the mixture sometimes exhibits the appearance of boiling. The solution is very caustic, and affords crystals by evaporation and cooling, which slightly detonate on hot coals, and leave a calx behind. This salt is deliquescent. The diluted muriatic acid acts on zinc with the same production

duction of hydrogen gas as the vitriolic; but this solution does not afford crystals.

The vegetable acids acquire from zinc a sweetish taste and stipticity. The action of the fluoric and boracic acids on zinc are not known. Water, impregnated with carbonic acid, dissolves a considerable proportion of zinc.

All the solutions of zinc in acids are precipitated by lime, magnesia, the fixed and volatile alkalis; the latter re-dissolves the precipitate if it is added in excess.

Zinc has the property of decomposing several neutral salts. If it is considerably heated with vitriolated tartar in a crucible, it decomposes the salt, and forms a liver of sulphur, in the same manner as the regulus of antimony does. In this experiment the metal seizes the oxygen of the vitriolic acid, and the acid passes into the state of sulphur, which the alkali dissolves. The hepar formed by this combination dissolves a portion of the calx of zinc. All the vitriols are likewise decomposed by zinc.

When pulverized zinc is added to fused nitre, or projected together with that salt into a heated crucible, a very violent detonation takes place. The activity of the inflammation is such, that portions of burning matter are thrown to a distance out of the crucible, in such a manner as to require precaution on the part of the operator. Only small quantities of the mixture should be cast into the crucible at once. The zinc burns by the assistance of the oxygenous gas afforded by the nitre, and

and is afterwards found in a calciform ſtate, more or leſs perfect, according to the proportion of nitre uſed. Part of the calx combines with the alkali, and forms a compound ſoluble in water.

Zinc decompoſes common ſalt, and alſo ſal ammoniac, by ſeizing the marine acid. The filings of zinc alſo decompoſe alum when boiled in a ſolution of that ſalt.

The relation of zinc to ſulphur is remarkable, as it is the only metal which does not unite with it in a reguline ſtate. M. Morveau, however, has diſcovered, that the calx of zinc unites eaſily with ſulphur by fuſion.

The regulus of zinc is capable of being united with that of arſenic, but it more readily unites with arſenic in its calciform ſtate. Zinc diſtilled with white arſenic deprived it of part of its oxygen, and was converted into a calx, while a correſponding quantity of arſenic was reduced to a regulus.

Zinc does not combine with biſmuth, and when theſe two metals are fuſed together, the biſmuth takes the lower place on account of its greater gravity, and may be ſeparated by a ſtroke of the hammer. It will not unite with nickel. Its volatility renders it extremely difficult to combine it with metals which are of difficult fuſion, as iron and copper. It is, however, united to ſeveral metals for particular purpoſes in the arts. It is added in ſmall quantities to tin, or to a mixture of tin and lead, in the compoſition of pewter, which it improves both in adding to the whiteneſs and brilliancy, and increaſing the hardneſs. It is employed in

in many alloys, particularly in tombác, prince's metal, and the various kinds of braſs. Fine filings of zinc are uſed to produce brilliant ſparks in fire-works. Some perſons have propoſed to ſubſtitute zinc for tin in lining copper veſſels; the latter metal, in conjunction with lead, having been ſuppoſed inſufficient to prevent the dangerous effects of the lead. Macquer allows that this metal ſpreads more evenly on the copper, is much harder, and leſs fuſible, than the lining of tin, but objects to it, becauſe it is ſoluble in vegetable acids, and has a conſiderable emetic power. Mr. De la Plance, however, has taken the ſalts of zinc, formed by the vegetable acids, in greater quantities than they can be contained in aliments which have been dreſſed in veſſels lined with zinc, without experiencing any dangerous effect. Experiments are yet wanting to prove the ſuperiority of zinc lining over that of tin.

Zinc is found in the following ſtates: It is ſometimes, though rarely, diſcovered native in flexible, greyiſh, and inflammable fibres. Zinc in its ore is generally in the form of a calx; when the ore contains no other metal but zinc it is never in any other form, but it is often mixed with other ores, which contain ſulphur and arſenic, and theſe muſt be evaporated by roaſting. The richeſt ores are compact and ponderous, and are called lapis calaminaris, or calamine, they are found in the pariſh of Holywell, in Flintſhire.

Margraff has aſcertained the quantity of zinc contained in different ſorts of calamine:

Calamine,

| | Parts. | | Parts. | |
|---|---|---|---|---|
| Calamine, from near Cracow - - - | 16 | gave | $2\frac{1}{2}$ | zinc. |
| Calamine, from England | 16 | —— | 3 | —— |
| —— from Breslaw | 16 | —— | $4\frac{1}{2}$ | —— |
| —— from Hungary | 16 | —— | $2\frac{1}{2}$ | —— |
| —— from Holywell | 16 | —— | 7 | —— |

In one hundred parts of lapis calaminaris were found eighty-four of calcined zinc, three of calcined iron, about one of pure clay, and twelve of siliceous earth, according to Bergman.

There is another species of mineral used in making brass called blende, mock lead, or black jack, which consists of zinc mineralized by sulphur, and sometimes by iron.

The method of making ordinary brass is as follows: —Copper in thin plates, or, which is better, copper reduced (by being poured when melted into water) into grains of the size of large shot is mixed with calamine and charcoal, both in powder, and exposed in a melting pot for several hours to a fire not quite strong enough to melt the copper, but sufficient to reduce the zinc, and convert it into vapours. These vapours penetrate the copper in proportion to the surface exposed to their action, changing its colour from red to yellow, and augmenting its weight in a great proportion. When they make brass, which is to be cast into plates, from which pans and kettles are to be made, and wire is to be drawn, they use calamine of the finest sort and in greater proportion than in the composition of common brass.

Tutty

Tutty is the flowers of zinc taken from the furnaces in which the ores containing this metal are wrought. It varies in colour and consistence according as the calx is more or less perfect, and is mixed with more or less of an argillaceous substance. Newman says, that the lapis tutiæ is composed of clay beaten up with a small quantity of lapis calaminaris.

Zinc and copper, when melted together in different proportions, constitute what are called pinchbeck, &c. of different shades of yellow. Margraff melted pure zinc and pure copper together in a great variety of proportions, and he found that eleven, or even twelve parts of copper, being melted with one of zinc, gave a most beautiful and very malleable tombac or pinchbeck.

CHAP.

# CHAP. XXVII.

## IRON.

*Extensive Utility of this Metal.—Its Properties.—Natural History of Iron.—Eagle-Stones.—Blood-Stones.—The Loadstone.—Emery.—Ochres.—Smelting of Iron.—Forging of Iron.—Making of Steel.—Tempering of Steel.—Cast Steel.—Great Disposition in Iron to unite with other Bodies.—Green Vitriol, how procured.—Prussian Blue.—Ink.—Inflammation of Sulphur and Iron.—Tinning of Iron.—Preparations of Iron used in Medicine.*

OF all metals, and I might perhaps be justified in adding, of all mineral substances, the most generally useful is iron. To specify its uses would be to produce a catalogue of every thing that contributes to the sustenance and the convenience of life. By the assistance of this metal we till the land, and obtain the fruits of the earth in greater abundance and perfection than we could by any other means; by its agency we are enabled to penetrate the earth itself, and procure whatever it contains that may be useful or ornamental to man; there is scarcely a mechanical trade, which could be conducted on the present principles without its aid, and many of them could not even exist were we deprived of it: even in domestic life our safety, our comfort, and our pleasure, all seem in some measure to depend on this most valuable production of the earth. As the quantity of this, as well as of some other minerals, which appear almost necessary

to social existence, must be limited, I have often thought that the want of a sufficient supply, which, on the supposition of the present system of things being continued for ever, must at some time necessarily take place, forms a forcible argument against the absurd and ignorant hypothesis of the eternity of the world.

The external appearance of this metal is well known, and its hardness and elasticity are seen in the various instruments and utensils which are formed of it.

It is the most sonorous of all the metals, except copper; but in specific gravity it is inferior to most of them, being only about seven times and a half the weight of water. Iron has a considerable smell, especially when rubbed or heated. It likewise has a very perceptible styptic taste.

Iron is very ductile, and may be drawn into wire as fine as a human hair; and it is so tenacious, that an iron wire of one tenth of an inch diameter will support a weight of fifteen hundred pounds. Iron may be ignited, or at least made sufficiently hot to set fire to brimstone, by a quick succession of blows with a hammer; but it requires a most intense heat to fuse it, on which account it is brought into shape by hammering while it is in a heated state. Iron is also possessed of another property, which supplies in a great measure the purposes of fusion. When pieces of common soft iron are heated to a certain degree, and are suddenly taken out of the furnace and exposed to the air, we observe their surface covered over with an appearance of varnish, which proceeds from

from the surface of the metal being partly fused. If two pieces of iron in this state are struck together, they unite very firmly, and this process is called welding. It is distinguished from all other metals by being attracted by the loadstone. Another property, which distinguishes iron from all other metals, is that of striking fire with flint. This phenomenon depends on the actual inflammation of small particles of the metal, which present a large surface to the action of the air, and which are heated by the friction which separates them from the mass, so as to dispose them to inflammation. These particles are seldom larger than the two hundredth part of an inch in diameter, and when examined by a magnifier, are found to be brittle, of a greyish colour, resembling the scales of burnt iron. Another proof of the inflammability of iron is, that iron wire, heated at one end, and plunged in a jar of oxygen gas, burns with considerable rapidity, and with a very brilliant flame.

Iron is by far the most abundant in nature of all the metals. It is not only contained in almost every fossil, particularly in those which are coloured, but makes a part of vegetable and animal matter. With respect to the ores of iron, however, as they are very numerous, it will be necessary only to notice those from which the metal may be extracted with advantage. In these ores iron exists either in the metallic or calciform state, or mineralized by different substances.

Native iron is known by its colour and malleability. It is very rare, and is only found occasion-

ally in iron mines. Some naturalifts think that thefe apparently native fpecimens of iron have been produced by art, and have been buried in the earth by accident.

In the Philofophical Tranfactions for the year 1788, vol. lxxviii. is an account of a mafs of native iron, weighing by admeafurement about three hundred quintals, which lies in the midft of a wide extended plain, in the middle of South America, in latitude 70° 28′ fouth, and at the diftance of feventy leagues eaft, one quarter fouth, from the hamlet of Rio Salado. It has the appearance of having been liquid, and bears the impreffion of human feet and hands of a large fize, as well as of the feet of large birds common in that country. The extraordinary fact of fuch a mafs of iron being found in the center of a vaft tract of level land, where there are no mountains, nor even the fmalleft ftone, within a confiderable diftance, projecting above the furface of the earth, is referred by the writer of this article to an ancient volcanic explofion, of which there are fome veftiges near it. The fame fuppofition is urged with equal probability to account for the production of another mafs of native iron, in the fhape of a tree with its branches, which the author afferts, on indubitable authority, is known to exift in thefe immenfe forefts. Some fpecimens of the iron were prefented to the Royal Society, who afterwards depofited them in the Britifh Mufeum. That large maffes of iron were really obferved in thefe fituations there is no reafon

to

to doubt, but I ſhould rather attribute the ſuppoſed impreſſions to accidental reſemblances.

The largeſt quantities of iron ores are in a calciform ſtate, as in ochres, bog ores, &c. which are diſpoſed in ſtrata, in the manner of ſtones. The ætites, or eagle ſtones, are a variety of the bog ores; they are in different forms, commonly oval or polygónous, compoſed of concentric layers, diſpoſed round a nucleus, which is frequently moveable in the centre of the ſtone. The hæmatites, or blood ſtones, are named from their colour, which is commonly red. The loadſtone is a dull iron ore, the varieties of which are diſtinguiſhed by their colour.

Emery is a grey or reddiſh iron ore; it is very hard and refractory, and is found in abundance in the iſlands of Guernſey and Jerſey. It is reduced into powder in mills, and in this ſtate is uſed to poliſh glaſs and metals. Spathoſe iron ore is a calx of iron combined with cretaceous acid; it is uſually of a white colour. Nature likewiſe preſents iron in a ſaline ſtate, united to the vitriolic acid, and forming green vitriol. This ſalt is particularly found in mines which contain pyrites. Iron is often found united to ſulphur, and then forms what are called martial pyrites. This metal is alſo found combined with arſenic, both being in the metallic ſtate. There is alſo a black iron ore, which is in ſome meaſure attracted by the magnet. Iron is ſometimes found in the form of a blue powder. In this ſtate it is called native pruſſian blue. It is mixed with vegetable earths, and eſpecially with turf. It

was discovered some years ago, that iron is often united with the phosphoric acid. The muddy or bog ores are sometimes of this nature.

The ores of iron do not afford the metal unless urged by a great heat. Some ores are melted without addition; but it is necessary to assist the fusion of others by calcareous matters. The limestones, the iron ore, and charcoal, are alternately thrown into the furnace, and the whole is covered with a layer of charcoal. The melted ore is reduced by the contact of the coaly matter, and is then suffered to run into a cavity usually formed in sand. The metal in this state is called crude or cast iron. A vitreous matter, called slag, passes after the iron, and consists of the stones which were added to facilitate the fusion. The metal thus obtained has not the least ductility; but it is deemed better in proportion as its colour is darker.

The cast iron is carried to be refined in a forge furnace, with a hollow hearth, in which it is surrounded with charcoal, where the fire is urged by bellows till the metal begins to soften. When it is in this state, it is repeatedly stirred, in order that it may present a larger surface to the air. By the action of the heat and air it emits sparks, which proceed from the consumption of a quantity of plumbago, or black lead, which is contained in the crude iron, and which it is commonly supposed to acquire from the fuel during the process of smelting *.

* It consists of carbon, with about one tenth of its weight of iron.

The

The iron, by this mode of refining, loſes, beſides the plumbago, a quantity of ſiderite, which Bergman ſuppoſed to be a peculiar metal, but which is now found to be a combination of iron and phoſphoric acid.

After the iron has been kept in this ſituation a certain time, it is carried to a large hammer, generally moved by water, where it is formed into bars. The hammering, by bringing the particles of the iron nearer together, preſſes out the impurities, and thus completes what was left deficient by the fuſion. This heating and hammering are repeated a number of times, till the iron has acquired the deſired degree of perfection. Crude iron loſes from a quarter to a third of its weight by the proceſs of refining, and is then called forged iron.

Steel is made by ſurrounding the bars of iron with a compoſition of which charcoal is the chief and only eſſential ingredient, and by keeping them in an intenſe heat a longer or ſhorter time, according to their thickneſs. They are then taken from the furnace, and plunged in cold water. The metal is now found to be more fuſible than it was before, but to have leſs ductility and ſoftneſs. Its texture is finer; it breaks ſhort; its fracture is always grey, and it has gained a ſmall increaſe of weight.

With reſpect to the chemical ſtates of the metal, in the three forms of caſt iron, forged iron, and ſteel, it appears that they chiefly depend on the quantities of plumbago. By ſolution in acids, it is found that caſt iron contains a large quantity of plumbago, that ſteel contains ſome of it, but that

the moſt malleable forged iron contains ſcarcely any; it therefore appears, that ſteel is in an intermediate condition between caſt iron and forged iron, and that, in making the former into the latter, the metal muſt paſs through the ſtate of ſteel. In ſome foreign works they actually manufacture ſteel by only ſtopping the proceſs of refining at a certain point. In theſe manufactories, however, they make uſe of an ore of uncommon purity; and the ſame proceſs does not ſucceed with ordinary ores, becauſe the metal obtained from theſe contains other impurities beſides plumbago, which cannot be ſeparated without reducing the iron to its malleable ſtate.

There are differences in the working of iron, according to the ores from which it is obtained, the cauſes of all of which have not been diſcovered. The preſence of phoſphoric acid, however, is known to produce a brittleneſs in iron when cold, which occaſions that ſort of iron to be called *cold ſhort* iron by the workmen. Phoſphoric acid is chiefly found in iron obtained from bog ores.

The workmen employed in tempering ſteel judge, by the different colours it aſſumes during the operation, of the degree of hardneſs it has acquired. That theſe colours may be obſerved, ſome part of the metal to be tempered ſhould be ſmooth.

The changes of colour depend on the calcination of the iron; for if the contact of air is prevented by the thinneſt covering of any oily matter, the effect is entirely prevented. The colour is firſt a pale yellow; if a piece of ſteel is then ſtruck off, it will be very hard. If the ſteel is left in the fire for a longer

longer time, it acquires a deeper yellow and more toughneſs, with ſcarcely any diminution in the degree of hardneſs; when brought down to the colour of watch ſprings, it is of the fitteſt temper for cutting wood. Steel, by being heated in this manner, becomes ſucceſſively white, yellow, orange, red, violet, and laſtly blue, which colour remains a conſiderable time; but if the heat is raiſed it becomes whitiſh.

Steel, ſtrongly heated while in the fire, aſſumes a red and ſparkling appearance, it next becomes very white and dazzling, and then burns with a ſenſible flame.

Caſt ſteel is nothing more than ſteel refined by fuſion. During this proceſs it throws up ſcoria, whilſt the metallic matter which remains is much harder than before, and its texture more uniform.

Iron is one of the metals which is acted on moſt powerfully by acids. But not only acids, but all ſaline ſubſtances ſeem to affect it, and even water is capable of acting on it ſo as to acquire from it a peculiar taſte. The tendency, indeed, which this metal has to combination with other bodies, particularly with oxygen, which occaſions ruſt, renders it incapable of permanency, and for this defect no ſufficient preventative has yet been diſcovered.

M. Lavoiſier, having expoſed iron with water in a glaſs veſſel over mercury, obſerved that the iron became ruſty, and that the water was diminiſhed in quantity. The iron was increaſed in weight, and there was a production of inflammable gas, ſo that in this experiment the water was decom-

poſed

posed by the iron, even without the presence of air.

Iron is acted on by the vitriolic, muriatic, and nitrous acids, with nearly the same phenomena as zinc. The products, however, are very different. The solution of iron in the vitriolic acid is of a green colour, and by evaporation produces the green crystals, well known under the names of sal martis, green vitriol, and copperas. The green vitriol used in commerce is obtained in the following manner: Pyrites, which are natural combinations of iron and sulphur, are exposed to the action of the air and rain in shallow pits lined with clay. After having been in this situation a week or a fortnight they grow hot and crumble down, and when carefully examined are found to contain small crystals. These are dissolved by the rain, and conveyed by pipes into a reservoir in a house, whence the liquor is pumped into a boiler made of lead. This liquor is found to have an excess of acid, which is remedied by casting pieces of iron into it when heated so as to simmer. By the addition of the iron a quantity of the earth of alum is also deposited. As the liquor cools, the greater part of the sal martis is deposited. By the exposure of the pyrites to the action of air and water, the sulphur attracts the oxygenous principle, and is thus converted into vitriolic acid. Sal martis is liable to the watery fusion; when exposed to a strong heat the acid begins to exhale, and as it exhales the natural colours of the calx of iron appear. It is first yellow, then orange, then red; if it is calcined to a greater degree, scarcely any of the acid

acid is left, and the calx remains of a deep purple colour, and is known under the name of colcothar of vitriol. The nitrous acid acts with so much violence on iron as to convert it into a brown calx. With the muriatic acid iron affords crystals of a livelier green colour than copperas, which will not, like copperas, part with the acid by the application of heat.

All solutions of iron, if exposed to the air, deposit part of the metal in the form of a calx. Alkaline salts precipitate the metal of a bluish grey colour, if the solution is fresh, but if long kept, in the form of a yellow powder. Mild vegetable alkali separates a yellow calx from the solution of iron in the nitrous acid, which soon becomes of a beautiful red orange colour. If the mixture is agitated during the effervescence, the precipitate is re-dissolved in much greater quantity than by the pure vegetable alkali. This solution is known by the name of Stahl's martial alkaline tincture.

But the most remarkable precipitation is that produced by a fixed alkali prepared with animal inflammable matter. The alkali is treated by mixing it, when dry, with twice its weight of blood, which has been indurated and reduced to powder; the mixture is put into a crucible, and a gentle heat applied; particular care must be taken to use the due degree of heat, which is known by the disappearance of a blue flame and smoke, which is at first observable on the surface. The matter thus prepared, being infused in water, affords an alkaline solution, which precipitates iron of a deep blue colour,

lour, especially if a little muriatic acid is added. The essential ingredients of the matter obtained by the above process seem to be a peculiar matter called prussic acid, and an alkali. The base of the prussic acid, according to M. Berthollet, consists of carbon, hydrogen, and azote. When the alkali, combined with this peculiar acid, is added to a solution of iron, the alkali takes the acid from the iron, while the prussic acid unites with the metal and falls to the bottom in the form of a blue powder. This effect of the alkali, thus prepared, is the foundation of the process for obtaining that valuable pigment, known by the name of Prussian blue.

Another singular, and not less useful circumstance, in the history of iron is the effect produced on it by astringent vegetable substances. The principle of astringency, which is now found to be a peculiar acid, called, in the new nomenclature, gallic acid, resides in a great number of vegetable matters, particularly oak galls, tea, &c. According to M. de la Metherie, however, the acid of galls is only a variety of the colouring principle. Galls are protuberances on the leaves of the oak, occasioned by the puncture of a particular insect Any of these substances, added to a solution of green vitriol, precipitates a fine black fecula, which may be suspended a considerable time in the fluid by the addition of gum arabic. Oak galls are commonly made use of in this process, which is that of making ink. The following proportions of these ingredients for making ink answer very well. One ounce of martial vitriol to three of powdered galls; to which one ounce

of

of powdered logwood may be added, to render the ink more permanent, and one ounce of gum arabic to ſuſpend the colouring matter. Let theſe be infuſed in a quart of water or vinegar for ten days, and ſhaken occaſionally, when the ink will be fit for uſe.

The colouring matter of ink ſeems to be produced from an union of the acid of the galls with ſome part of the iron in a calciform ſtate. A ſmall quantity of any of the mineral acids deſtroys the colour of the ink, by diſſolving the iron, which was imperfectly precipitated; and this colour is again reſtored by the addition of an alkali, which takes away the acid. The black fecula of ink is not magnetical; but it may be converted into a brown magnetic calx by heat. Ink becomes blacker by expoſure to the air, which acidifies more completely the principle combined with the iron; but ancient writings become more and more yellow in conſequence of the decay of the vegetable matter. Their legibility may be reſtored by the uſe of infuſion of galls, or gallic acid. The beſt method, however, of reſtoring the legibility of ancient writings, conſiſts in ſpreading a ſolution of the Pruſſian alkali thinly with a feather over the traces of the letters, and then to touch it gently, and as nearly upon or over the letters as can be done, with a diluted acid, by means of a pointed ſtick.

The only eſſential ingredients of ink are green vitriol, galls, and water. Dr. Lewis has made many uſeful experiments on the proportions of theſe ingredients which produce the beſt ink. He found that

that equal quantities of galls and green vitriol produced the deepest colour, but not the most durable; he found, that by increasing the quantity of the galls the colour was rendered more durable; that with three times the weight of the galls to one of the vitriol, the colour was very permanent; but that if the proportion of galls was increased beyond this, the colour was too weak; in this case the writing was much refreshed by washing it with a solution of vitriol. He also endeavoured to ascertain the best proportion of the fluids to the vitriol and the galls. He first tried water, and found that by considerably diminishing the quantity of it the ink was more durable, but too thick for use. He found that all waters were much the same; but that white wine and vinegar made a more durable ink; but that both these were exceeded by a decoction of forty ounces of water to one of logwood, which of itself gives a permanent red stain. If the colour of the ink should fail, that of the logwood will remain, and it produces, with ink, a much stronger and blacker colour than usual; for the common colour of ink is a purplish blue, which, mixed with red, makes a deep black. He did not find any vegetable astringent equal in all respects to galls.

Mr. Nicholson states an objection to the use of vinegar in the making of ink, which is, that it acts so strongly on the pens that they continually require mending. Ink is very apt to become mouldy, which is best remedied by the addition of a few cloves reduced to powder; for hot aromatics

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are excellent preſervers of animal and vegetable matters.

Iron detonates ſtrongly with nitre. It appears to combine with alkalis by fuſion. The calx of iron combines with earths, aſſiſts their fuſion, and imparts a green colour to the glaſs. Iron has a remarkable attraction for ſulphur, and combines with it either by the action of heat or moiſture. A mixture of equal parts of iron filings and ſulphur, made into a paſte with water, becomes hot, emits watry vapours and inflammable air, in a little time the maſs takes fire, and, by attracting the oxygen of the water, becomes converted into green vitriol, in the ſame manner as pyrites. This is the mixture uſed in the production of an artificial earthquake, which will be ſpoken of more fully under the head of earthquakes.

With reſpect to the relations of iron to the other metals, there is little worthy of note, except its attraction for tin, on which is founded the proceſs of tinning iron. In ſome countries iron is made into plates, by being repeatedly heated and ſubmitted to the action of a heavy hammer. In England, however, the plates are not hammered, but rolled out to the proper dimenſions, by being put between two cylinders of caſt iron, caſed with ſteel. When the iron plates have been either hammered or rolled to a proper thickneſs, they are ſcoured with a weak acid, which renders their ſurface perfectly clean and bright, and takes off all the ruſt, which would prevent the adheſion of the tin to their ſurface; they are then wetted with a ſolution of ſal ammoniac, and plunged

ed into a veſſel containing melted tin, the ſurface of which is kept covered with pitch or tallow to prevent its calcination. The tin adheres to each ſide of the plate, and intimately combines with the iron to a certain depth, which renders the tinned plates leſs diſpoſed to harden by being hammered, and forms an excellent defence for the iron againſt the action of air and moiſture.

Biſhop Watſon propoſes it as a queſtion of ſome importance, whether iron of a greater thickneſs might not be advantageouſly tinned? He deſired a workman to break off the end of a large pair of pincers, which had been long uſed in taking the plates out of the melted tin; the iron of the pincers ſeemed to have been penetrated through its whole ſubſtance by the tin; it was of a white colour, and had preſerved its malleability. It is uſual to cover iron ſtirrups, buckles, and bridle bits, with a coat of tin, by dipping them, after they are made, into melted tin; and pins, which are made of copper-wire, are whitened, by being boiled for a long time with granulated tin in a ley made with alum and tartar. On theſe circumſtances he founds two queries; 1. Whether the iron bolts, uſed in ſhip-building, would be preſerved from ruſting by being long boiled in melting tin? 2. Whether it would be poſſible to ſilver iron-plates, by ſubſtituting melted ſilver for melted tin?

It is cuſtomary, in ſome places, to alloy the tin uſed for tinning iron plates with about one-ſeventieth part of its weight of copper. Too much copper renders the plates of a blackiſh hue, but when added

added to tin in a proper proportion, it enables the manufacturers to lay on a thinner coat of tin without injury to the colour. This practice, however, is rather of prejudice to the duration of the plates. When the tin is heated to a great degree, the covering which it imparts to the iron is thinner but more even. The plates are apt, from this cause, to have yellow spots on them; but this inconvenience may be removed by boiling the plates for two or three minutes in lees of wine, or, where they cannot be had, sour small beer, or other similar fluids, may probably be used with the same success.

Iron is justly considered as a valuable article of the materia medica, and while its utility is considerable, it is entirely free from those deleterious and debilitating effects which proceed from most of the other metals that are used as medicines. The ferrum vitriolatum, or green vitriol, has been already mentioned. The ferri subigo is made by merely exposing iron filings to the air, and moistening them with water till they are converted into rust. The ferrum tartarisatum is prepared by mixing one part of iron-filings with two of crystals of tartar moistened with water, and exposing them to the air for eight days. In this preparation the iron is chiefly brought to the saline state by means of the acid of tartar. The ferrum ammoniacale, or flores martiales, is made by mixing one pound of iron filings with two of sal ammoniac, and applying a brisk heat. The sal ammoniac sublimes and carries up so much of the iron as to be changed to a deep orange colour. The flores martiales may be made

equally well with the colcothar of martial vitriol as with the iron-filings. The tinctura ferri ammoniacalis, or ammoniacal tincture of iron, is made by digesting one pint of proof spirit of wine with four ounces of ferrum ammoniacale. The tinctura ferri muriati is prepared by dissolving the rust of iron in the muriatic acid, and adding a quantity of rectified spirit of wine. Wine of iron is obtained by digesting rust of iron with Spanish white wine, in the proportion of an ounce to a pint, for a month.

# CHAP. XXVIII.

## TIN.

*General Properties of Tin.—Granulated Tin.—Natural History of Tin.—Its Union with the Acids.—Use of Tin in improving the red Dyes.—Smoaking Liquor of Libavius.—Aurum Musivum.—Combinations of Tin with other Metals.—Different Species of Pewter.—Putty.—Application of Tin in dying.—Use in Medicine.*

TIN, when its surface is fresh, is bright, and with respect to whiteness holds a middle place between lead and silver. Tin is the lightest of all metals, being only about seven times heavier than water. It produces a cracking noise when it is bent, though it yields easily. It is very soft, and, probably from this cause, it is scarcely at all sonorous. It is considerably malleable, and may be reduced beneath the hammer into laminæ thinner than the leaves of paper (commonly known by the name of *tin foil*) which are of great use in several arts, particularly the foiling of looking glasses. Its degree of toughness is such, that a wire of tin of the tenth of an inch in diameter supports a weight of forty-nine pounds and an half without breaking.

Tin is the most fusible of metals, and melts at a little above the heat of 400°, which is long before it becomes red hot. In passing from the fluid to the solid state it remains a short time in an intermediate condition, in which it has little more cohesion

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than wet ſand, and may be broken by a blow of a hammer, or by agitation, into grains. Tin is eaſily calcinable in an obſcure red heat; it at firſt forms a grey pellicle; and in a ſtrong heat it calcines with inflammation into a white powder. The calx of tin reſiſts fuſion more than that of any other metal; from which property it is uſeful to form an opake white enamel, when mixed with pure glaſs in fuſion.

It is obſerved by miners, that though tin is the lighteſt of the metals, its ores are ſome of the heavieſt. Tin is ſeldom or never found in the metallic or reguline ſtate. The ores are often cryſtallized, and of different colours. Thoſe which are of a reddiſh colour generally contain a large proportion of iron. There alſo is a ſulphureous tin ore of a brilliant colour, ſimilar to that of zinc, or golden, like aurum muſivum. The more tranſparent ores of tin often contain arſenic, and this is ſeparated, almoſt entirely, by repeated roaſtings.

In order to reduce the ores of tin, they are firſt cleanſed from foreign admixtures by ſorting, pounding, and waſhing. In the ſmelting of the ore, care is taken to add a larger quantity of fuel than is uſual in the revival of other metals, and to avoid a greater heat than is neceſſary to reduce the ore, in order that the loſs by calcination may be as little as poſſible. Almoſt all the tin uſed in Europe comes from Cornwall, which has been famous for its tin mines from the remoteſt periods of hiſtory.

Tin is five times as dear as lead, and as a ſmall quantity of the latter mixed with a large quantity of the

the former is with difficulty discovered, the temptation to adulterate tin is great, and the fear of detection small. Bishop Watson states, in his Chemical Essays, that in Cornwall the purity of tin is ascertained, before it is exposed to sale, by what is called its *coinage*. The tin, when smelted from the ore, is poured into quadrangular moulds of stone, containing about three hundred and twenty pounds of metal, which, when hardened, is called a *block* of tin; each block of tin is coined in the following manner:—the officers appointed by the duke of Cornwall assay it, by taking off a piece of one of the under corners of the block, partly by cutting and partly by breaking, and if well purified, they stamp the face of the block with the impression of the seal of the duchy, which stamp is a permission for the owner to sell, and at the same time an assurance that the tin so marked has been purposely examined, and found merchantable *.

The concentrated vitriolic acid acts on tin with the production of sulphureous vapours, part of the oxygen of the acid, as is usual in the solutions of metals in their reguline state, being abstracted. The acid dissolves about half its weight of tin, but not without the assistance of heat. The solution is very caustic. The nitrous acid is decomposed by tin, as it is by most of the metals, with great rapidity. The tin is converted into a white calx, which it is very difficult to reduce. M. de Morveau has remarked the formation of a quantity of volatile

* Borlase's History of Cornwall, p. 183.

alkali during the ſolution of tin in the nitrous acid. This is probably owing to a combination of the azote, produced by the acid, with the hydrogen, derived from the decompoſition of the water contained in the menſtruum. The advocates for the phlogiſtic hypotheſis, however, ſay, that the hydrogen is the phlogiſton of the tin ſet at liberty during the ſolution.

The fuming muriatic acid acts ſtrongly on tin, inſtantly loſing its colour and its property of emitting fumes. The muriatic acid diſſolves more than half its weight of tin, and does not let it fall by repoſe. By evaporation it produces brilliant and very regularly formed needles, which ſlightly attract the humidity of the air. The oxygenated muriatic acid diſſolves tin very readily, and without the leaſt ſenſible effervescence. Aqua regia, conſiſting of two parts nitrous and one muriatic acid, combines with tin with effervescence and the developement of much heat. The ſolution of tin in aqua regia is uſed by dyers to heighten the colours of cochineal, gum lac, and ſome other red tinctures, from crimſon to a bright ſcarlet, in the dying of woollens. By firſt diſſolving tin in the marine acid, and then boiling the ſolution with nitrous acid diſtilled from manganeſe, M. Hermſtædt has ſucceeded in acidifying tin to ſuch a degree as to convert it into an acid; it had then the form of a white powder, ſoluble in three times its weight of water.

Tin has a ſtronger affinity with the muriatic acid than mercury has, and decompoſes the corroſive mercurial

mercurial sublimate. To effect this, the tin is first divided by the addition of a small portion of mercury; equal parts of this amalgam and the corrosive sublimate are triturated together, and the mixture exposed to distillation in a glass retort with a very gentle heat. A colourless liquor first passes over, and is followed by a thick white vapour. The vapour becomes condensed into a transparent fluid, which continually emits a thick, white, and very abundant fume. It is called the fuming liquor of Libavius, and is a combination of the muriatic acid and tin. The smell of this fluid is very penetrating, and excites coughing. The vapours are not visible without contact of air, and seem to consist of a peculiar gas, which is decomposable by air, and which then deposits the calx of tin in the same manner as the hepatic gas of Bergman deposits sulphur by the contact of air. M. de Fourcroy proposes it as a query, whether this elastic fluid is a composition of the oxygenated muriatic acid and tin? When water is added to this fuming liquor in a certain quantity, it becomes solid, and ceases to emit fumes. It is found that this concrete substance, when rendered fluid by an increase of temperature, is capable of dissolving more tin without the escape of hydrogen gas. Hence it appears that the oxygen necessary for the solution of this additional quantity of metal is not derived from the water but the acid, and that the acid to impart it must be in an oxygenated state. The experiments of M. Adet have thrown much light on the nature of the

fuming liquor of Libavius, and are publiſhed in the Annales de Chemie.

Tin is capable of decompoſing all the vitriolic neutral ſalts. Tin has a conſiderable attraction for ſulphur, and eaſily unites with it, when in a ſtate of fuſion, into a black maſs. Aurum muſivum is a combination of tin and ſulphur, obtained by a particular proceſs. Arſenic cannot eaſily be united to tin, on account of the volátility of the former metal. Cobalt unites by fuſion with tin, and forms an alloy in ſmall cloſe grains of a light violet colour. Biſmuth in ſmall quantities, as well as zinc, impart a firmneſs and whiteneſs to tin. Mercury diſſolves tin with great facility, and in all proportions.

The uſes of tin are very numerous. It is applied to many purpoſes in the arts. Its amalgam with quickſilver or mercury is applied to ſilver looking-glaſſes. The uſe of tin in covering plates of iron has been already ſpecified; and it is alſo employed in lining the inſide of copper veſſels. It enters into the compoſition of bronze and bell metal. It is the chief ingredient in the compoſition of pewter. Pewter conſiſts of tin united to ſmall portions of other metallic ſubſtances, ſuch as lead, zinc, biſmuth, and antimony. We have three ſorts of pewter in common uſe; they are diſtinguiſhed by the names of *plate*; *trifle*; *ley*. The plate pewter is uſed for plates and diſhes; the trifle chiefly for ale pints, quarts, &c. and the ley-metal for wine meaſures and other coarſer uſes. Our very beſt pewter is ſaid to conſiſt of one hundred parts of tin to from ten to ſeventeen of antimony.

mony. To this compoſition the French add a little copper. In general the lighteſt pewter is the beſt. The inferior kinds are heavier and ſofter, from a quantity of lead with which they are adulterated. Putty is prepared from the white calx of tin. The ſolution of tin in aqua regia has been already mentioned as uſeful in dying. When it is mixed in the dyer's bath it forms a precipitate, which carries down the colouring matter, and depoſits it on the ſtuff which is to be dyed ſcarlet. The operation of tinning copper will be afterwards deſcribed. The powder of tin has been uſed as a remedy againſt worms in large doſes, and therefore the ſcruples which have been entertained againſt the uſe of veſſels lined with tin muſt be wholly without foundation. Tin has been analized by many chemiſts, with a view to diſcover the quantity of arſenic contained in it. The reſults of theſe experiments have been by no means uniform. The largeſt proportion, however, which has been detected in any tin uſed in commerce, is a grain in an ounce, or one five hundred and ſeventy-ſixth part of the compound; but more frequently no arſenic whatever has been diſcovered.

## Chap. XXIX.

### LEAD.

*General Properties of Lead.—Red Lead.—Litharge.—Natural History of Lead.—Smelting Lead Ores.—Union with Acids.—Plumbum Corneum.—White Lead; how made.—Sugar of Lead.—Union with other Metals.—Common Solder.—Uses of Lead.—Great Danger from leaden Vessels.—Devonshire Colic.—Means of detecting Lead in Liquors.—Medical Uses of Lead.—Uses of its Calces in the Arts.*

THE appearance of this metal is well known. It is so soft as to be cut with a knife without much difficulty. It is neither sonorous nor, elastic. It has very little tenacity, and therefore cannot be drawn into fine wire. It spreads easily under the hammer, but cannot be extended into very thin leaves like gold, silver, and tin. Its specific gravity is rather greater than that of silver, being eleven times heavier than water, and it is exceeded in this respect by only three metals, gold, platina, and mercury. Lead melts at the five hundred and fortieth degree of Fahrenheit's thermometer, before it becomes red hot.

Lead, like tin, at a certain point between its fluid and solid states, possesses very little cohesion, and may be separated by a smart blow with a hammer into grains, which are used in assaying the ores of gold and silver.

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Lead, ſoon after it is melted, acquires a film on its ſurface, which preſents in ſucceſſion a variety of colours. This film becomes thicker, and of a grey colour, by the continuance of the calcination, and is then called plumbum uſtum. If the firſt pellicle is removed, another is quickly formed, and in this way almoſt the whole of the lead may be converted into a greyiſh powder tinged with green and yellow. This powder, being ground in a mill and waſhed, becomes of a more yellow colour. By further expoſure to a moderate heat, aſſiſted by the reverberation of the flame of the fuel on the ſurface of this calx, it gradually aſſumes an orange, and then a bright red colour, and is thus, in about forty-eight hours, converted into the ſubſtance called minium, or *red lead.* If lead is, in the phraſe of the chemiſts, urged with a more violent and ſudden heat, the appearances which it exhibits are different. It is firſt converted into a flaky ſubſtance, called litharge, which, by the proceſs juſt deſcribed, may be converted into minium, but which, by an increaſe of heat, becomes fluid, and acts ſo powerfully as a ſolvent on earthy ſubſtances as quickly to make its way through ordinary crucibles.

All theſe calces of lead may be eaſily reduced to the metallic ſtate, by melting them in contact with inflammable ſubſtances. In calcining and reducing ſixty hundred weight of lead, there is found to be a loſs of eight hundred. This loſs was explained by the old chemiſts on the ſuppoſition of the eſcape of a volatile ſubſtance called by them mercurial earth, but which was never proved to have any exiſtence.

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The loſs, however, ought to be attributed in ſome meaſure to the evaporation of part of the lead itſelf, and partly to the imperfection of the proceſs, as it is ſeldom performed ſo accurately as to reduce the whole of the calx.

Lead is very rarely found native. It is ſometimes found in the form of a calx, called native ceruſe, or lead ochre, or in that of lead ſpar of various colours, and which are in general either rhomboidal or cubical. Lead combined with ſulphur is called galena, which is compoſed in general of laminæ which have nearly the colour and aſpect of lead, but are more brilliant, and very brittle. A great variety of theſe ores have been diſcovered, which it will not be neceſſary to enumerate. Lead, in ſome inſtances, has been found combined with various acids; the vitriolic, the phoſphoric, the carbonic, and the arſenical. The ores of lead very commonly contain ſilver, and ſometimes antimony.

In ſmelting lead ores the ſulphur is diſſipated for want of a proper apparatus for collecting it. According to biſhop Watſon's experiments, the Derbyſhire lead ores contain in general from one-ſeventh to one-eighth part of their weight of ſulphur. One of the chief circumſtances to be attended to in the ſmelting of lead ores, particularly ſuch as contain much ſulphur, is to keep them for ſome hours in a moderate heat, by which that ſubſtance may be gradually diſſipated. After this the fire muſt be raiſed to fuſe the maſs completely, by which the metal flows through the ſcoriæ, and is collected in the cavity at the bottom of the furnace. The

ſcoriæ being then thickened by the addition of lime, ſo that they may be raked aſide, a ſtopper is drawn out and the lead ſuffered to flow into an iron pot, whence it is laded into moulds, which form it into the maſſes called pigs of lead.

Lead is ſoluble in the concentrated vitriolic acid, by the aſſiſtance of heat only. The lead then forms, with the vitriolic acid, a ſubſtance ſcarcely ſoluble in water. It ſeems to have a peculiar affinity with this acid, and leaves all others to combine with it, which is not the caſe with the other metals.

The nitrous acid acts ſtrongly on lead. When the acid is concentrated, it corrodes the lead into a white calx; but if it is conſiderably diluted, it diſſolves the lead. This ſolution does not afford a precipitate on the addition of water. Its cryſtals, obtained by cooling, are of an opake white. This ſalt decrepitates in the fire, and melts with a yellowiſh flame when laid on ignited charcoal. The calx, which is at firſt yellow, is quickly reduced into globules of lead. The vitriolic acid added to this ſolution combines with the metal, and forms a precipitation. The marine acid, in the ſame manner, ſeizes the lead, and forms a combination, which, if expoſed to heat, melts into a maſs of a brown colour, called plumbum corneum, from ſome reſemblance to the combination of the ſame acid with ſilver, called argentum corneum.

The acetous acid, or vinegar, acts on lead, particularly when applied to it in ſteam, in which proceſs the action of the air probably aſſiſts that of the acid. To procure white lead, ſheets of lead are rolled up

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ſpirally ſo as to leave the ſpace of about an inch between each coil, and placed vertically in earthen pots, which have ſome good vinegar at the bottom. The pots are covered, and expoſed to a gentle heat for a conſiderable time by ſurrounding them with horſe-dung. The ſteams of the vinegar circulate in the veſſel, and attach themſelves to the ſurface of the lead, converting it into white flakes, which come off when the lead is uncoiled. The remaining lead is again expoſed to the ſteams of the vinegar, till another cruſt is formed, and the proceſs is repeated till its whole ſubſtance is converted into the white flaky matter called ceruſe, or white lead.

Such are the deleterious effects of lead, when taken into the human body, that the wretched labourers in white lead works are ſeldom known to ſurvive more than three years, when they expire in excruciating pain from the Devonſhire colic, loſe the entire uſe of their limbs, or gradually pine away by a waſting maraſmus. In a well regulated community ſuch works ought to be entirely prohibited, or at leaſt only carried on by the worſt of felons, whoſe lives would be otherwiſe forfeited.

Lead, after being thus reduced to the ſtate of ceruſe by the fumes of the acetous acid, may be eaſily diſſolved in the ſame acid in a fluid ſtate, and the ſaline matter thus formed, is then called, from its ſweet but aſtringent taſte, ſugar of lead.

To have this ſalt of lead in the form of tranſparent cryſtals, it is neceſſary to uſe much acid; if there is not a redundancy of acid, moſt of the cryſ-

tals are ſmall and mealy. This may be remedied by diſſolving them again in diſtilled vinegar, and repeating the cryſtallization. In this manner ſo much of the acid may be united to the metal as to change the appearance of the ſalt to that of an oily fluid. This metallic ſalt, like others, may be decompoſed by an alkali. In all theſe caſes the precipitates of lead are white, but the calces are coloured.

The ſaccharum ſaturni, or ſugar of lead, may be decompoſed by heat alone, for, when expoſed to a gradual heat, the acid riſes in a very concentrated ſtate. This proceſs is attended with the remarkable phenomenon of the production of a quantity of ardent ſpirit. By the phlogiſtic hypotheſis this fact admitted of explanation, by ſuppoſing that the principle of inflammability of the metal combined itſelf with a portion of water, contained in the acetous acid, and thus formed alcohol, or ſpirit. Upon M. Lavoiſier's principles, however, it may be much better accounted for. It has been proved by him, that alcohol is a combination of hydrogen, charcoal, and a ſmall quantity of oxygen. Now all theſe principles exiſt in vinegar, the baſis of which is hydrogen and charcoal, brought to the ſtate of an acid by their union with a large proportion of oxygen. The chief difference, therefore, between vinegar and alcohol is, that the former contains much more oxygen. As part of the oxygen, however, after this operation, is ſtill retained by the lead, which is not reduced to its metallic form, it is very natural

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to suppose that part of the fluid which passes over should be reduced to the state of alcohol.

Nitre, heated with lead, calcines it into a yellow substance, but without producing deflagration. Sal ammoniac and common salt are decomposed by being heated with the calces of this metal, but the neutral salts, in general, are not acted on by it. Sulphur readily dissolves it by the assistance of heat, and produces a brittle compound of a deep grey colour and brilliant appearance. Phosphorus may be united with lead, and forms with it a malleable and soft compound, not very different in appearance from lead itself.

Lead combines with bismuth, and affords a metal of a fine close grain, which is very brittle. The alloy of lead with arsenic has not been examined. Nickel, manganese, cobalt, and zinc, do not unite with lead by fusion. With antimony it forms a brittle alloy, with some brilliant facets. Mercury dissolves lead with the greatest facility. Lead unites very easily with tin. Two parts of lead with one of tin form an alloy more fusible than either of the metals taken separately, and which is, therefore, used by plumbers as a solder.

Lead is used for a great number of economical purposes. Leaden vessels, however, are very apt to communicate injurious properties to all fluids which are kept in them for any length of time, and should wholly be rejected in the management of such fluids as contain an acid capable of acting immediately on the metal, and of dissolving so much as irreparably to

injure

injure the constitutions of persons who are in the habit of using them. Instances in which lead received into the body has produced the lingering and painful disorder called the painter's colic, or the colic of Poitou, are too numerous to leave any question as to the pernicious effects of this metal. The liquors in which an admixture of lead is most to be apprehended are, cyder, wines, and rum. In Devonshire, from the great use of cyder, and the improper methods of making it, by which, either through carelessness or design, lead becomes dissolved in it, the disorder above mentioned prevails so much, as to have obtained the name of the Devonshire colic.

It is unfortunately the case, that lead dissolved in vinous liquors is capable of imparting a rich and agreable flavour to them, and even of restoring them after they have become considerably acidulated. The temptation to use lead, therefore, in this way is great; and so long as dealers are ignorant of the pernicious effects of this metal, or want honesty to prefer the safety of their customers to their own profit, there is no reason to hope that the habit of occasionally using it will be abolished. The adulterating of wines in this manner was so common a few years ago in France, that it was unsafe for strangers to use the wines which were sold at their inns. It is very desirable to be furnished with the means of detecting this pernicious ingredient, and the following are recommended by an author, whose speculations even on the most common subjects have ever been directed to the public good, and are al-

ways productive of public advantage *: Boil together, in a pint of water, an ounce of quick lime and half an ounce of flowers of brimstone, and when the liquor, which will be of a yellow colour, is cold, pour it into a bottle, cork it up, and reserve it for use. A few drops of this liquor, being let fall into a glass of wine or cyder containing lead, will change the whole into a colour more or less brown, according to the quantity of lead which it contains; if the wine is wholly free from lead, it will be rendered in some measure turbid by the liquor, but the colour will be rather a dirty white than a blackish brown.

In general, a solution of common liver of sulphur will precipitate the lead, but unfortunately iron as well as lead is precipitated by both these tests, and it is said that many honest wine-merchants have been ruined by this means, by having unjustly fallen under the suspicion of adulterating their wines with lead. M. Hannemann has published a paper in the Journal de Physique, in which he assures us, that the following liquor, whilst it does not precipitate iron, will precipitate lead and copper of a black colour, and arsenic of an orange. Mix equal parts of oyster shells and crude sulphur in fine powder, and

* Bishop Watson. This excellent and truly respectable author, this great ornament of the English church, will, I flatter myself, forgive the very free and frequent use I have made of his incomparable Essays. He has ever been

"Mihi magnus Apollo."

"My guide, philosopher——"

and, if I was not afraid of presuming too far, I would add the conclusion of that well known line.

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put them into a crucible; apply a brisk fire in an air furnace, so as to make the crucible of a white heat for about fifteen minutes. The mass, when cold and powdered, should be kept in a bottle well corked. To prepare the liquor, put one hundred and twenty grains of this powder, and one hundred and eighty grains of cream of tartar, into a very strong bottle, fill it with water, let it boil for an hour, and then cool. Cork the bottle, and frequently shake up the ingredients. After it has stood for some hours to settle, pour off the clear liquor, and put it into little bottles, which contain about an ounce, having previously dropped into each twenty drops of marine acid. Cork them close by means of wax mixed with a little turpentine. One part of this liquor, mixed with three parts of the wine supposed to contain noxious metallic particles, will discover, by a black precipitate, the smallest particle of lead, copper, &c. but will not affect the iron contained in it. Pure wines are not discoloured by the addition of this liquor.

The deleterious effects of lead are not confined to its action on the stomach. Men who work in the manufactories for the different preparations of lead are liable to complaints very similar to those who drink liquors containing lead. Painters are so liable to this complaint, from the lead contained in paint, that it has obtained, on this account, the name of the painter's colic.

Lead is the most powerful article in the materia medica in restraining hemorrhages and excessive discharges, but its use is so dangerous that it is not

very often employed internally by physicians. The preparations of lead are, however, highly beneficial, without being generally dangerous, as ingredients in plasters and other external applications, particularly in the well known Goulard's extract.

The calces of lead are used in making some kinds of glass, of which they increase the solidity, and to which they impart a kind of unctuosity which fits them for being cut and polished with less danger of breaking. Lead enters particularly into the composition of flint glass, and the compositions called pastes, or artificial gems. The chief defect of flint glass is, that it is apt to be of unequal density, which renders it difficult to find pieces of any considerable dimensions free from striæ. Litharge is also employed by potters for glazing their ware.

The uses of red and white lead, as pigments, are well known The common red wafers are coloured with red lead, as may be easily seen by holding one of them in the flame of a candle, when the lead will be reduced, and appear in little globules; these wafers should, therefore, never be left in the way of children, as they may be induced to swallow them, and may consequently subject themselves to all the ill effects arising from this fatal poison. The best red wafers are coloured with vermilion.

CHAP.

# CHAP. XXX.

## COPPER.

*General Properties of Copper.—Its Natural History.—Turquoise Gem.—Smelting and refining of Copper.—Antique Statues preserved by the Green Rust.—Union with Acids.—Blue Vitriol.—Colouring of Guns.—Cuprum Ammoniacum.—Verdigris.—Union with Metals.—White Copper.—Pinchbeck.—Gun Metal.—Bell Metal.—Metal of ancient Statues.—Bronze.—Speculums of Reflecting Telescopes.—Pot Metal.—Tinning of Copper.*

COPPER is a metal of a peculiar red colour, and when its surface is fresh and clean it has a considerable degree of splendor. It is hard, ductile, and malleable to a considerable degree, and remarkably sonorous. It has a peculiar and unpleasant smell, particularly when rubbed. Its taste is styptic and nauseous. Its tenacity is such, that a copper wire of one tenth of an inch in diameter is capable of supporting a weight of about three hundred pounds. Its fracture exhibits the appearance of small grains. Its gravity is about nine times that of water.

Copper has a great degree of strength and rigidity, approaching to that of iron. It is not inflammable like iron, and is therefore used in gunpowder works, instead of that metal. It does not admit, like iron, of being welded, but this defect is compensated by its greater fusibility, by which it

may be always formed into the desired shape. It requires for its fusion about the same heat as gold and silver. When in fusion, for which it requires a strong white heat, it appears of a blueish green colour, which arises from a flame of that colour on its surface. By a very violent heat it boils, and is volatized partly in the metallic state. Copper, in a heat far less than is sufficient to melt it, becomes calcined at its surface, and exhibits various colours. In a greater heat than is sufficient to produce this effect, its surface is converted into thin scales, which may be easily scraped off.

Copper is sometimes found native, having the metallic splendour, the malleability, and all the properties of ordinary copper. It has sometimes the form of plates, sometimes that of fibres or branches, and is sometimes crystallized. Copper, in its metallic state, is sometimes found deposited on ores of iron, in which case it must be considered as having been separated from native vitriol of copper by the superior attraction of iron for the vitriolic acid. The native solutions of copper often deposit that metal in a calcined state in beds of calcareous earth. The turquoise stone is the tooth of an animal, penetrated with the blue calx of copper. Copper is generally found, however, contained in ores. These are frequently mineralized by sulphur. What are improperly called the vitreous ores of copper are of this kind; they are brown, red, and grey, and these colours are frequently mixed with a greenish or violet tinge. These melt easily, are very ponderous, may be scratched or even cut with

a knife,

a knife, and are very rich in metal, as an hundred pounds of them usually yields from eighty to ninety of copper. The azure copper ore differs from the former chiefly in containing a considerable quantity of iron. The grey copper ores, which have not much splendor, consist of copper, sulphur, arsenic, and some iron. What are called copper pyrites contain in reality more iron than copper, but yield enough of the latter metal to answer the expence of working them; they are generally of a yellow and brilliant aspect. Copper is also, in some specimens, found united with slate, pitcoal, zinc, and antimony.

Copper is separated from its ores by different processes, according to the nature of those ores. If they contain much sulphur, after being pounded and washed, they are roasted in the open air to dispel the sulphur, which in a great measure supplies the want of other fuel. The ore is afterwards roasted once or twice more with wood, and is melted in an open fire into a mass called a mat of copper. In this state it still contains a large quantity of sulphur, which the workmen continue to expel by repeated roastings and fusions, till the metal acquires a certain degree of purity, and is called black copper, which is somewhat malleable, but still contains sulphur, iron, and generally some other impurities. In order to get entirely rid of these, the copper is hastily fused with three times its weight of lead. The lead unites with the copper and expels the iron, and the imperfect metals, which happen to be mixed with the copper,

are expelled by cupellation. The copper is afterwards refined, by keeping it heated in crucibles for a confiderable time, fo that it may throw up all the foreign fubftances it ftill contains in the form of fcoriæ. It is examined, from time to time, by immerfing iron rods in it, which become coloured with a fmall quantity of copper, and its purity is judged of by the brilliant rednefs of thefe fpecimens.

Copper is not fo eafily acted on by the air as iron. In fituations, however, where it is expofed to the action of moift air, it becomes gradually covered with a green ruft or calx, which is fapid and foluble in water. This ruft never penetrates into the fubftance of copper, but feems rather to contribute to the prefervation of its internal parts, as may be feen in antique medals and ftatues of this metal.

Copper does not unite with earthy matters; its calx, however, promotes their fufion, and forms with them glaffes of a deep brown. Cauftic fixed alkalies, digefted in the cold with filings of copper, affume, after a time, a light blue colour, the copper becoming covered with a powder of the fame colour. Copper, treated in the fame manner with volatile alkali, produces, in a few hours, a deep and moft beautiful blue, the quantity of copper taken up being very inconfiderable. From the ftrong blue colour produced by the action of copper and volatile alkali, they become excellent tefts of the prefence of each other in any body, fluid or folid.

Copper is in general eafily acted on by acids. The vitriolic acid, however, does not act on it

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unleſs concentrated and aſſiſted by heat; it then corrodes the copper into a brown matter of a thick conſiſtence, which, by the addition of water, affords a ſolution of a deep blue colour. If this ſolution is evaporated to a certain point, and ſuffered to cool, long rhomboidal cryſtals are afforded of a deep blue colour, called vitriolated copper, or blue vitriol; it appears therefore that vitriolic acid forms, with iron, green cryſtals; with zinc, white cryſtals; and with copper, blue cryſtals.

Copper may be obtained from the ſolution of blue vitriol, by dipping into it pieces of iron. The vitriolic acid diſſolves the iron in preference to the copper, and depoſits the latter, in its metallic form, on the ſurface of the iron. Upon this circumſtance is founded the proceſs for browning fowling pieces. The barrels are moiſtened with a ſolution of blue vitriol, which diſſolves the iron to a very inconſiderable depth, and depoſits in its place a thin lamina of copper.

Blue vitriol has a ſtrong ſtyptic taſte, and is in ſome degree cauſtic. Expoſed to heat it parts with its water of cryſtallization, melts, and becomes of a pale blue colour. A ſtrong heat is required to ſeparate from it the vitriolic acid, which adheres more firmly to copper than iron. Blue vitriol is decompoſed by magneſia and by lime. If the mild vegetable alkali is poured into a ſolution of blue vitriol, a precipitate is formed of a pale blue colour, which, however, becomes green by expoſure to air: in this experiment no effervescence takes place, and we may therefore conclude that the

the carbonic acid of the mild alkali unites with the calx of copper. Volatile alkali precipitates the solution of blue vitriol, in the same manner, of a blueish white colour; but the mixture very soon becomes of a deep blue colour, which happens from the alkali re-dissolving the precipitate. In order to obtain the *cuprum ammoniacum*, which has been recommended as a remedy for epilepsy, add volatile alkali till the whole precipitate of copper is redissolved, then set the solution before a fire in a flat vessel, and let it gradually evaporate, which should be done with a heat not exceeding that of the human body; the matter which remains at the bottom, in the form of a crust, must be rubbed in a mortar, that it may be intimately mixed.

The blue vitriol of the shops is made by means of the action of sulphur upon copper; these are gently calcined together; the sulphur attracts the oxygen of the atmosphere, and unites with the copper into a soluble powder, which is afterwards crystallized into blue vitriol.

A beautiful green paint may be precipitated from blue vitriol, by means of white arsenic dissolved in water together with vegetable alkali.

The nitrous acid dissolves copper with great rapidity, without the assistance of heat, with the production of a large quantity of nitrous gas. Part of the metal falls down in the form of a calx, and the filtrated solution, which is of a much deeper blue colour than the vitriolic solution, affords crystals by slow evaporation. This salt is more corrosive than vitriolated copper; it so powerfully at-

tracts

tracts the humidity of the atmoſphere that it deliqueſces, unleſs kept in cloſe veſſels or in a very dry place. When melted in a crucible it emits large quantities of nitrous vapour and becomes brown, in which ſtate it is merely a calx of copper. In a dry and hot air this ſalt becomes covered with a green efflореſcence. It detonates ſlightly on burning coals.

The muriatic acid acts with great difficulty on copper in its metallic ſtate, but diſſolves its calces with conſiderable rapidity. This may be eaſily accounted for from the ſtrong attraction which the baſe of the muriatic acid has for oxygen, ſo that it will not part with any of it to oxygenate the metal, and no metal is ſoluble in acids without being firſt oxygenated. When, however, the metal has been prepared for ſolution by an union with oxygen, that is by being calcined, the acid then diſſolves it, and adheres very cloſely, ſo that it is with great difficulty ſeparated by heat. The muriatic ſolution of copper is of an agreeable green colour, and affords cryſtals of the ſame, and in this particular differs remarkably from the vitriolic and nitrous combinations of copper, which are of a deep blue.

The vegetable acids diſſolve copper when calcined, but ſcarcely act on it in its metallic ſtate. It is a curious circumſtance, which has never been ſufficiently explained, that vegetable acids act more powerfully on copper when cold than when they are heated. Thus pickles, or even lemon juice, may be boiled in clean copper veſſels without danger; and yet, if left for a few hours, when cold, in copper veſ-

fels, they are apt to contract a metallic impregnation fufficient to produce dangerous effects. This fact has by fome chemifts been attributed to the fteams of the boiling fluid keeping off the air, which is thought to affift the action of the acids.

Verdigris is a very beautiful green ruft or calx of copper, much ufed by painters, and prepared in large quantities near Montpelier in France. The procefs for making verdigris was thus defcribed by M. Monnet, of the Royal Society of Montpelier, about the year 1750. Vine ftalks, well dried in the fun, are fteeped, during eight days, in ftrong wine, and afterwards drained; they are then put into earthern pots, and wine is poured upon them; the pots are kept carefully covered. The wine undergoes the acetous fermentation, which in fummer is finifhed in feven or eight days, but requires a longer time in winter, though this operation is always performed in cellars. When the fermentation is fufficiently advanced, which may be known by obferving the inner furface of the lids of the pots, which, during the progrefs of the fermentation, are continually wet by the moifture of the rifing vapours, the ftalks are to be taken out of the pots. The ftalks are by this method impregnated with all the acid of the wine, and the remaining liquor is only a very weak vinegar. The ftalks are now drained fome time in bafkets, and layers of them are put into earthern pots with plates of Swedifh copper, fo difpofed that each plate may reft on and be covered with layers of ftalks. The pots are covered with lids, and the copper is thus left expofed

to

to the action of the vinegar for three or four days or more, in which time the plates become covered with verdigris. The plates are then taken out of the pots, and left in the cellar three or four days, at the end of which time they are to be moistened with water, or some of the weak vinegar above mentioned, and left to dry. When this moistening and drying of the plates has been repeated three times, the verdigris will be found to have increased considerably in quantity, and it may then be scraped off for sale.

A solution or erosion of copper may be obtained by employing ordinary vinegar instead of wine, as is directed in the above process. It would not, however, have the unctuosity of the best verdigris, which quality is necessary for painting. Good verdigris cannot be prepared, except with a vinous acid, or a solvent partly acid and partly spirituous. Accordingly the success of the operation depends chiefly on the degree of acetous fermentation to which the wine has been carried.

By distilling verdigris, the acetous acid may be separated in a concentrated state, and of a strength equal, or perhaps superior, to the muriatic acid.

Copper is capable of a very slight detonation with nitre. It decomposes sal ammoniac, and at the same time the volatile alkali is in some measure resolved into its constituent parts, azote and hydrogen.

Sulphur and phosphorus may be united to copper; they deprive it of its metallic splendor, and change it to a black colour. If plates of copper are stratified

ſtratified in a crucible with ſulphur, they unite, and form a compound which is uſed in the dying and painting of calicoes. Liver of ſulphur and hepatic gas have a ſtrong action on copper; the former diſſolves the metal by the dry, as well as by the humid way; the latter ſtrongly colours the ſurface, but its effect has not yet been well examined into. Oils alſo diſſolve copper, particularly thoſe of an aromatic kind.

There are few metals which will not form alloys with copper. A metallic compound is made with arſenic in imitation of ſilver, but it ſoon tarniſhes. In treating of zinc, the proceſs for making braſs has been deſcribed. Pinchbeck is a kind of braſs made in imitation of gold. Copper is the baſe of gun metal and bell metal. Gun metal is ſaid to conſiſt of copper, with about one tenth part of tin; bell metal, of copper with about one fifth of tin. It may in general be obſerved, that a leſs proportion of tin is uſed for making church bells than clock bells, and that a little zinc is added for the bells of repeating watches, and other ſmall bells.

Copper, in a ſtate of fuſion, is liable to a violent exploſion if touched with any humidity. In the caſting of bells and cannon they are particularly careful to have the moulds dry; for if the leaſt moiſture finds acceſs, it is ſuddenly converted into vapour, and by its expanſion throws the metal to a conſiderable diſtance, to the great danger of the perſons preſent.

The beſt poſſible proportions of copper and tin, for the above purpoſes, have never, I believe, been

accurately

accurately ascertained. The metallic compound used by the Romans for their statues and plates for inscriptions, is handed down to us by Pliny the naturalist. They first melted a quantity of copper; into the melted copper they put a third of its weight of old copper, which had been long in use; to every hundred pounds weight of this mixture they added twelve pounds and an half of a mixture composed of equal parts of lead and tin. Tin melted with copper forms the compound called bronze. Of this compound the specific gravity is always greater than would be deduced by computation from the quantities and specific gravities of its component parts. There seems to be a happy relation between these metals, which fits them for forming, in conjunction, compounds of great firmness, density, and closeness. From these properties they admit of an excellent polish, and Pliny accordingly informs us, that the best looking glasses of his time were made of a composition of copper and tin. But the attention of philosophers is more particularly directed to the mixture of copper and tin, on account of its being the substance of which the speculums of reflecting telescopes are made. Mr. Mudge found, after a number of trials, that fourteen ounces and an half of grain tin, with two pounds of copper, made the best composition for this purpose; an addition of half an ounce more of the tin rendered the composition too hard to be properly polished.

Pot metal is made of copper and lead, the latter being one fourth or one fifth of the weight of the former. Lead, however, does not seem to have any remarkable

remarkable attraction for copper, and does not promote its fusion, unless the lead is heated to a high degree; the copper then dissolves with some degree of effervescence. On allowing the compound to cool, the copper separates again, and forms little grains in the mass, through which the lead remains dispersed. It is easy to separate the lead again from the copper, if the mass is exposed in a furnace; for the lead melts first and leaves the copper; the lead, however, which runs off at first, contains some of the copper, which may be easily separated by melting the lead and taking off the scum, which contains the copper. Silver is separated from copper by melting the latter with three times its weight of lead; the lead is then melted out, and carries with it the silver. The silver is afterwards separated from the lead by the calcination of the latter metal.

From the bad effects which have been experienced from impregnations of copper in aliments dressed in copper vessels, it has become a very general custom to cover these vessels with an internal coat of some other metal. The method of tinning iron has been described, and that of tinning copper is very similar, except that the composition for covering the surface of copper consists of about one part of lead to two of tin, whereas iron is covered with tin alone. Zinc has been recommended as a substitute for tin in these operations, and has the advantage of superior hardness. The method of tinning copper vessels is by making their internal surface perfectly bright, and then washing them with a solution of sal ammoniac. The vessel is next

next heated, and the tin or metallic mixture is melted and poured into it, and being made to flow over every part of the surface of the vessel, it incorporates with the copper, and when cold remains united with it. Rosin, or pitch, are sometimes used to prevent the tin from being calcined, and the copper from being scaled, either of which circumstances would prevent the adhesion of the tin. Bishop Watson estimated the quantity of pure tin which is used in tinning a definite surface of copper, and found that half an ounce of tin was spread over two hundred and fifty-four square inches, or somewhat less than a grain of tin on each square inch; but the same author suspects, that not a quarter of a grain of tin is spread over a square inch in the ordinary mode of tinning, and therefore recommends it as a necessary caution against the coat being rubbed off, and the copper becoming exposed, to make it as thick as possible, and to use tin nearly pure.

A very excellent method of tinning, and one much practised in England, is, to make use of pure tin, and hammer it on the copper. It seems probable, however, that when copper vessels are kept well scoured, that no danger will arise from them in the dressing of animal food, or even of vegetable aliments, unless suffered to remain in the vessels when cold.

## Chap. XXXI.

### MERCURY.

*Great Attraction of this Metal for the Matter of Heat.—Quicksilver rendered solid; malleable.—General Properties of Quicksilver.—Hydrargyrus calcinatus.—Natural History of Mercury.—Cinnabar.—Native Vermilion.—Action of Acids on this Metal.—Turbith Mineral.—Red Precipitate.—White Precipitate.—Corrosive Sublimate.—Calomel.—Keyser's Pills.—Æthiop's Mineral.—Vermilion.—Amalgams.—Gold made brittle by Mercury.—Mode of gilding Metals.—Use of Quicksilver in extracting the precious Metals from the Earth.—Making of Looking Glasses.—Conditions necessary for the Operation of Mercury on the human Body.*

THE circumstance which most remarkably distinguishes mercury, or quicksilver, from the other metals, is its strong attraction for heat, so that it retains the state of fluidity at the ordinary temperature of the atmosphere, and at the temperature of 600 degrees of Fahrenheit is converted into vapour; few of the other metals, therefore, melt at so low a point as that at which mercury boils and is volatilized. It was long taken for granted that there was something peculiar in mercury, which rendered it necessarily fluid; but the academicians of Petersburg have proved that this is an erroneous idea, and shewn that mercury differs from other metals merely in the degree of heat at which it passes from its solid to its fluid state. The congelation of mercury has been effected in a variety of instances by the help of the nitrous acid and snow, or pounded ice, commonly called the freezing

ing mixture, and the congelation is found to take place at the thirty-ninth degree below 0 of Fahrenheit's thermometer. Mercury, in its solid form, is found to have considerable malleability, but this cannot be proved to its fullest extent, because the hammering of it produces very soon a degree of heat sufficient to melt it.

Mercury being a metal in a state of fusion, always affects the form of globules when it is divided; and when it is confined in a bottle, its surface is convex, from the strong attraction of its particles for each other. If the vessel, however, in which mercury is confined, is metallic, its surface appears concave, from the tendency which it has to unite itself to the sides of the vessel, which attraction overcomes that between its own particles.

When mercury is submitted to that degree of heat at which it is volatilized, and is at the same time exposed to the action of atmospherical air, it is gradually converted into a calx of a red colour, the hydrargyrus calcinatus of the London pharmacopeia. A greater heat, however, revives this metallic calx, and at the same time the vital air is again extricated.

Mercury is not sensibly acted on by exposure to air, but by long continued agitation it becomes partly converted into a very fine black powder. The mercury is not changed in this experiment, unless, perhaps, it should be found that it absorbs some part of the vital air contained in the vessel in which it is confined. By a slight heat,

or by trituration in a warm mortar, it may be made to reſume its uſual fluidity and brilliancy.

Mercury is found in the earth, either in its native metallic ſtate, or combined with ſulphur, when it is called cinnabar. Running mercury is found in globules, or larger maſſes, in friable earths or ſtones, and moſt commonly in the clefts or cavities of its ores. It is more frequently, however, imbedded in calcareous earths or clays of different colours, from which it may be ſeparated either by trituration or lotion, the ſmaller globules coaleſcing by mutual contact into larger; or by diſtillation.

More mercury is found in the ſtate of cinnabar than in its metallic form. This ore conſiſts of mercury and ſulphur combined together in different proportions. Cinnabar is ſometimes found in the form of a brilliant red powder, and is then called native vermilion, ſometimes in an indurated ſtate, and though generally red, has been ſometimes obſerved of a yellowiſh or blackiſh caſt. It it is moſtly opake, but ſome ſpecimens are as tranſparent as a ruby.

Mercury is too volatile to admit of the ſulphur being ſeparated from it by roaſting; theſe ſubſtances are both ſo volatile that they would riſe together. In order to ſeparate mercury from its ore it is neceſſary to add quick lime, or iron filings, unleſs ſome ſubſtances of a ſimilar nature happen to be naturally mixed with it; the maſs is then ſubmitted to diſtillation, and the calcareous earth, or iron filings, by ſuperior attraction, detain the ſulphur, while the mercury comes over in the ſtate of

vapour,

vapour, and is condensed in the receiver. Different cinnabars yield from three parts to seven parts in eight of their weight of mercury. Mercury has sometimes been found united with the muriatic and vitriolic acids, and with the ores of some other metals. It is thought to be not abundant in nature; but this opinion may be partly owing to its volatility, which may prevent it from being discovered in many minerals that may contain it. Most of the mercury in commerce is afforded by the mines of Idria in the Austrian dominions, Almaden in Spain, and Guancavelica in Peru.

The vitriolic acid does not act on mercury unless concentrated and considerably heated; it then corrodes it into a white mass, and the vitriolic acid is rendered partly volatile by the abstraction of oxygen. The greatest part of this mass, which weighs considerably more than the mercury made use of, is a calx of mercury united to a small portion of vitriolic acid, but part of it is a perfect salt, formed by the union of the vitriolic acid and mercury. If boiling water is added to it, it assumes a bright lemon colour, which is owing to the abstraction of the vitriolic acid, the presence of which rendered the mass white. The more boiling water is used the yellower is the remaining powder, which, after repeated effusions of water, is found to have no causticity, and to be nearly a pure calx of mercury. This is the substance known under the name of turbith mineral. The water, which has been poured on the vitriolic mercurial

mass, is found to contain a considerable quantity of vitriolic acid united to the calx of mercury.

The nitrous acid is decomposed by mercury with the greatest rapidity. Strong nitrous acid will take up its own weight of mercury in the cold, and this solution will bear to be diluted with water. If the solution is made by the assistance of heat, a much larger quantity is dissolved; but a precipitate is produced by the addition of water. If cold water is employed, a white precipitate is afforded, but if hot water the precipitate is of a yellow colour, and greatly resembles the turbith mineral produced by the vitriolic acid. If acid is added to the solution produced by heat, it is not decomposed by water. This solution is very ponderous and acrid, and stains the skin of a deep purple, inclining in appearance to black, a portion of the mercury being precipitated by the animal matter, while the acid acts on it. Caustic alkali, added to this solution, precipitates a pure calx; mild alkali, a calx combined with carbonic acid. The volatile alkali precipitates the mercury in the form of a dark grey powder. When this precipitate is examined, it is found to contain a quantity of mercury in its metallic state. If this matter is dried and rubbed on pure gold, it turns white, by which we may discover small quantities of mercury in the metallic state. The near approach to the metallic state, observed in the precipitate afforded by the volatile alkali, seems to be owing to the presence of hydrogen, which is one of the constituent principles of volatile alkali, and which has a strong attraction for oxygen.

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The precipitates of mercury, formed by alkaline intermediums, have a property discovered by M. Bayen, which must not be passed over in silence. They detonate like gun-powder, when exposed in an iron spoon to a gradual heat, after having been triturated in the quantity of half a drachm, with six grains of flowers of sulphur: after the detonation, a violet powder remains, which may be sublimed into cinnabar.

The nitrous acid may be separated from mercury by heat alone. Its first effect is to evaporate the watery parts; after this the acid flies off in deep coloured fumes; as the acid evaporates the calx becomes yellow, then of a deep red, but when removed some time, orange. This is the red precipitate of the shops. The nitrous acid, therefore, as in the case of other metals, though it acts with more rapidity, adheres with less force to the mercury than the vitriolic acid, which acts slowly and with difficulty. This proceeds, as was before mentioned, from the ease with which the nitrous acid is decomposed, so as to afford to metals the oxygen which is necessary to render them soluble.

The muriatic acid has no action on mercury in its metallic state, because it cannot part with the oxygen necessary to calcine the metal. It has, notwithstanding, a very strong attraction for mercury, and dissolves it with great readiness when the latter is previously reduced to the state of a calx. If a small quantity of muriatic acid is poured on a nitrous solution of mercury, it seizes the metal, and forms a salt, which is precipitated in the form of a

whitish coagulum, which, when dried, is called white precipitate, and is a kind of corrosive sublimate. The marine salts, with base of alkali, or of any saline terrestrial substance, such as lime, magnesia, &c. produce the same effect, except that in this case, though the precipitate is the same, the nitrous acid, instead of being left uncombined, unites with the basis of the marine salt which was employed.

If mercury, corroded by the vitriolic or nitrous acids, and dried, is mixed with powdered sea salt, and exposed to heat, a double attraction takes place; the nitrous or vitriolic acid deserts the metal to unite with the fixed alkali of the common salt, while the muriatic acid seizes upon the mercury, and forms a metallic salt, which, in the degree of heat necessary for the operation, proves volatile, and, rising in vapour, is condensed in a solid form in the upper and cool part of the vessel employed. This is the hydrargyrus muriatus, or corrosive sublimate, which is a very acrid and powerful preparation of mercury.

The mild preparation, called calomel, is obtained by rubbing three parts of mercury, in its metallic state, with four of corrosive sublimate, till they form a greyish powder; the mass is then sublimed*, and forms a substance like corrosive sublimate, but more ponderous, and of a more silvery appearance. The ingredients, however, are not sufficiently

* Made volatile, or raised in vapour, by the application of heat.

mixed

mixed by the firſt ſublimation; they muſt be rubbed together again and ſublimed; and theſe proceſſes muſt be repeated at leaſt three times.

The converſion of the corroſive ſublimate into the milder ſubſtance, calomel, may be explained on the following principles:—In the corroſive ſublimate, the muriatic acid is found to be combined with a very large quantity of oxygen, which renders it extremely active. By the addition of mercury, a quantity of this ſuperfluous oxygen is abſtracted, for the calcination of the additional metal; and the whole maſs, therefore, contains the acid not only in a milder ſtate, but the ſame quantity of acid is diffuſed through a larger maſs of the metal.

Ponderous earth, magneſia, and lime, decompoſe the corroſive ſublimate, and precipitate a mercurial calx. The phagedenic water, made uſe of as a corroſive by ſurgeons, is made by throwing half a drachm of corroſive ſublimate, in powder, into a pound of lime water; a yellow precipitate is then formed, which renders the liquor turbid.

Acids and neutral alkaline ſalts produce no change on corroſive ſublimate, but it contracts an intimate union with ſal ammoniac without decompoſition. The ſal ammoniac renders corroſive ſublimate very ſoluble. The calx hydrargyri alba of the London Pharmacopeia is obtained from this combination. A quantity of ſal ammoniac is diſſolved in diſtilled water; an equal weight of corroſive ſublimate is then added; when this is diſſolved, fixed vegetable alkali is added, which produces a white precipitate. In this operation the fixed alkali diſ-

engages

engages the volatile alkali of the ſal ammoniac, which precipitates the mercury in the form of a white calx. This preparation is chiefly uſed in liniments externally. It is ſometimes adulterated with ceruſe, as the red precipitate is with minium. The fraud may be diſcovered by expoſing a ſmall quantity to heat in a ſpoon; if pure they will be entirely diſſipated, but if they contain lead, or other impurities, theſe matters will remain behind.

If the ſalt formed by the combination of acetous acid with the fixed vegetable alkali, commonly called regenerated tartar, or kali acetatum, is added to the ſolution of quickſilver in the nitrous acid, a double exchange takes place; the alkali unites with the nitrous acid, while the acetous acid enters into combination with the mercury, and is precipitated. This precipitate (being purified by ſolution in hot diſtilled water and filtration) has nearly the ſame medical properties as calomel, and is ſaid to form the baſis of Keyſer's pills. The acetous acid does not act on mercury unleſs when reduced to the ſtate of a calx.

As mercury is commonly, in a ſtate of nature, combined with ſulphur, ſo it may be artificially united to it with great eaſe. When one part of this metallic fluid is triturated with three parts of flowers of ſulphur, the mercury gradually loſes its metallic appearance, and is converted, by its union with the ſulphur, into a black powder, called Ethiop's mineral. This combination is more quickly effected by mixing the mercury with melted ſulphur. When this compound is expoſed to a conſiderable degree of

of heat it takes fire, the greater part of the ſulphur burns, and after the combuſtion a matter remains, which, when pulverized, is of a violet colour. To convert this powder into cinnabar it is put into matraſſes *, which are heated till their bottoms become red, and kept in this ſtate for ſeveral hours, till it appears that the matter is entirely ſublimed. The Dutch prepare, in the large way, the cinnabar employed in the arts. When much divided by levigation † it has a brilliant red colour, and is called vermilion.

Mercury has the property of uniting itſelf to many of the metals, by penetrating their ſubſtance, and rendering them more or leſs ſoft, according to the proportion of mercury employed. If the proportion of quickſilver is very great, the mixture is like quickſilver, and is only diſtinguiſhed from it by an appearance of foulneſs. If a ſmaller quantity is uſed, the maſs is ſoft like butter; if ſtill leſs, it is ſolid but brittle. Theſe mixtures are called amalgams. It readily combines in this way with gold, ſilver, lead, tin, biſmuth, and zinc, but not eaſily with arſenic and copper, and ſcarcely at all with iron, platina, nickel, or cobalt. Its action on the other metallic bodies has not been aſcertained.

A piece of gold, being rubbed with quickſilver, is ſoon penetrated by it, and is rendered ſo fragile

* Veſſels uſed in chemical operations, of glaſs or earthenware, generally of the ſhape of an egg, and open at the top, the necks are long or ſhort, as occaſion may require.

† Reduced to a fine powder.

that

that it may be eaſily broken. A gold ring, which has become ſo tight on the finger that it cannot be drawn off, may be eaſily removed in this manner. Gold, united with quickſilver in certain proportions, forms a kind of paſte. On this property is founded the proceſs of gilding in *or moulu*. A ſmall quantity of this paſte is ſpread upon the ſurface of the copper which is to be gilded in *or moulu*, and the metal is then expoſed to heat. Quickſilver evaporates in a far leſs degree of heat than is ſufficient to melt either gold or copper; when, therefore, the mixture of gold and quickſilver is expoſed to heat, the quickſilver is driven off in vapour; but the gold, not being ſuſceptible of evaporation, remains attached to the ſurface of the copper, and undergoing the operations of burniſhing, &c. the latter is gilded, or gilt. This method of gilding copper, by means of gold and quickſilver, was known to the Romans. The ſurface of iron cannot be covered in the ſame way with gold; but the iron, by being moiſtened with a ſolution of blue vitriol, as in the proceſs for browning firelocks, and being thus covered with a lamina of copper, becomes as ſuſceptible of being gilded as if its whole ſubſtance was copper.

It is this property which quickſilver has of uniting with the precious metals, and diſſolving them, which has rendered it ſo ſerviceable in the extraction of them from the earth with which they are mixed. The earth or ſtones, in which gold and ſilver are contained, being reduced to powder, are mixed with quickſilver, which diſſolves every particle of the precious

precious metals without contracting the leaſt union with the other matters; the quickſilver is then driven off by heat, and, being condenſed in the receiver, is again employed in the ſame proceſs. The gold and ſilver are ſeparated from each other by proceſſes, which will be deſcribed in treating of thoſe metals. Since the diſcovery of the American gold mines, the conſumption of quickſilver has been much increaſed. Hoffman concludes, from calculation, that fifty times as much gold as quickſilver is annually extracted from the bowels of the earth.

Looking glaſſes are covered on one ſide with an amalgam of tin and mercury. Tin, being beaten into thin leaves, is called tin foil; on tin foil, evenly diſpoſed on a flat ſtone, quickſilver is poured, and ſpread with a feather until its union has brightened every part of it; a plate of glaſs is then cautiouſly ſlid upon the tin foil, in ſuch a manner as to ſweep off the redundant quickſilver which is not united to the tin; weights are then placed on the glaſs ſo as to preſs out ſtill more of the quickſilver, and in a little time the tin foil, thus united to the quickſilver, adheres ſo firmly to the glaſs that the weights may be removed without any danger of its falling off. About two ounces of quickſilver are uſed in covering three ſquare feet of glaſs.

In order to make mercury capable of acting on the animal body, it is neceſſary that it ſhould undergo ſome preparation; for its particles muſt be very minutely divided before they can enter the veſſels. Thus, if we apply quickſilver to a capillary tube, the

the attraction of its particles for each other is ſo ſtrong that they will not riſe in it; but minute diviſion is not the only circumſtance neceſſary to its activity, for Ethiop's mineral and cinnabar taken into the body have very little if any effect. Oxygenation ſeems to be the moſt eſſential circumſtance; for in whatever way this is effected the mercury becomes very active *.

Mercury, in paſſing through the body, is reduced to the metallic ſtate, and, exuding through the pores, ſometimes attaches itſelf to the gold of watches, rings, ſleeve-buttons, or ear-rings, and renders them white.

* Does not the effect of ſulphur, in diminiſhing the activity of mercurial preparations, depend on its ſuperior attraction for oxygen, by which it has a tendency to reduce the mercury to the metallic ſtate?

CHAP.

# CHAP. XXXII.

## SILVER.

*Character of the perfect Metals.—General Properties of Silver.—Vegetation of Silver.—Natural History of Silver.—Assaying of Silver.—Cupellation.—Lunar Caustic.—Fulminating Silver.—Luna Cornea.—Diana's Tree.—Green Gold.—Standard Silver Coin.—Plating with Silver; how performed.—French Plate.*

OF the different metallic substances only three have been dignified by chemists and mineralogists with the appellation of perfect, viz. silver, gold, and platina. These are distinguished from the other metals by their weak attraction for oxygen, which enables them to retain their purity and metallic splendor in situations in which other metals become gradually covered with rust or calx. Silver is the whitest of all metals, and is possessed of great brilliancy; it is harder than gold; in weight it is exceeded by gold, platina, quicksilver, and lead; its gravity being only about ten times that of water. Its malleability is so great, that a grain of it reduced to ordinary silver leaf measures about fifty-one square inches, in which state it is not more than the hundred and sixty thousandth part of an inch thick, which, however, is considerably more than one third thicker than gold leaf. Its tenacity is so considerable, that it may be drawn into wire about half the thickness of a fine human hair, and a wire of one tenth of an inch in diameter will support the weight of two hundred

hundred and ſeventy pounds without breaking. It is very ſonorous, but in hardneſs and elaſticity it is not equal to copper. It hardens under the hammer, but very readily loſes that hardneſs by heating.

Silver, expoſed to the heat of the moſt powerful burning lenſes, is partly vitrified and partly volatilized in fumes, which are found, when received on a plate of gold, to be ſilver in the metallic ſtate. It is likewiſe ſaid to have been partly calcined by twenty ſucceſſive expoſures to the heat of the porcelain furnace at Sêves. This, however, may be doubted, as ſilver does not undergo any degree of calcination by expoſure to heat, even with the addition of nitre. Silver melts in the firſt degree of white heat, and appears in the fire like the fineſt quickſilver. When it is haſtily cooled, it exhibits a curious phenomenon, called vegetation; for we diſcover from different parts of its ſurface ramifications and branches like thoſe of trees which ſprout out with a ſtem. The reaſon of this appearance ſeems to be the irregular contraction which the ſilver undergoes in paſſing from the fluid to the ſolid ſtate. The melted ſilver ſuffers the firſt commencement of congelation at its ſurface; by theſe means a cruſt is formed, which by its ſudden contraction compreſſes the fluid ſilver within; thus a protuberance is formed, which, congealing in its turn, contracts and preſſes the intermediate fluid through its cruſt into branches.

The air alters ſilver very little, unleſs it contains ſulphureous vapours, which it often does, from the putrefaction of animal ſubſtances or the exhalations of

of drains, or of sulphureous mineral waters. This metal, therefore, becomes somewhat tarnished by long continued exposure to the atmosphere, and in time becomes covered with a thin purple or black coating, which, after a long series of years, has been observed to scale off from images of silver exposed in churches, and was found, on examination, to consist of silver united to sulphur.

Silver is often found in its native state, and may be known by its brilliancy and ductility. It is sometimes met with in irregular masses, sometimes it the form of capillary threads or fibres, and sometimes in that of branches, formed by octahedrons inserted one into the other. It is also often dispersed in a quartzose gangue.* Native silver is sometimes found alloyed with gold, copper, iron, or regulus of antimony; but native gold much oftener contains silver than native silver does gold. Silver is not naturally found in the state of calx.

The vitreous ore of silver is composed of that metal and sulphur. It is the richest of the silver ores, and yields from seventy to eighty pounds of the metal in the hundred weight. It is of a blackish grey colour, resembling lead; some specimens are brown, greenish, yellow, &c.; it may be cut with a knife, and is sometimes crystallized. If it is exposed to a heat not sufficient to melt it, the sulphur is dissipated, and the virgin silver is obtained in fibres.

* A quartzoze or sparry crystallization, often found inclosing the ores of metals, and therefore called the matrix or rider.

The red silver ore contains arsenic as well as sulphur. It is a heavy shining substance, sometimes transparent, sometimes opake, but commonly crystallized. It is often of a deep red colour on the outside, but appears paler within. It affords about half its weight of silver. If it is exposed to a fire carefully managed, and capable of igniting it, the silver is reduced, and forms capillary fibres, similar to native silver.

There is a silver ore containing arsenic, cobalt, and iron, mineralized by sulphur. This ore sometimes yields half its weight of silver; it varies in its appearance, being sometimes of a grey and brilliant aspect, but often of a dull and tarnished colour, with efflorescences of cobalt. The goose dung ore belongs to this species. The grey ore of silver contains a large quantity of copper. The black silver ore, called nigrillo by the Spaniards, seems to be a middle state between native silver and some of its ores, or those ores in a state of imperfect decomposition. The corneous silver ore is a natural combination of silver and muriatic acid with a small quantity of vitriolic acid. Silver is also found in considerable quantity in the ores of other metals, particularly those of antimony, zinc, lead, and copper.

In the assaying of silver ores different processes are used, according to their nature. When found in its metallic state, nothing more is necessary than to separate it from the earthy or stony matter in which it is embedded. With this view it is first exposed to heat, to render the stony matter friable.

The

The maſs is then mixed and ground with quickſilver. Thus the ſilver is converted into an amalgam, which, from the intimate union of the particles of the metals, is ſpecifically heavier than quickſilver itſelf. The ſtony matters are now eaſily waſhed off, without loſing any of the metal. The quickſilver is afterwards partly ſeparated by ſqueezing it through a piece of leather, and the remainder by diſtillation. Sulphureous ſilver ores require to be firſt roaſted, and then mixed with a quantity of flux. In order to ſeparate lead, copper, iron, &c. from ſilver, a particular proceſs is employed, which is called cupellation, from the veſſel in which it is performed, called a cupel, and which is chiefly formed of calcined bones, and is very porous. The metallic maſs containing ſilver is mixed with a conſiderable quantity of lead, and then expoſed on the cupel in a ſtate of fuſion. The lead is vitrified and abſorbed into the cupel, carrying with it the imperfect metals, and the ſilver remains behind on the cupel in a pure ſtate.

The vitriolic acid acts on ſilver as on the other metals, with the aſſiſtance of heat; it then corrodes it into a white maſs, which is ſoluble in water, and by evaporation affords ſmall cryſtals.

The nitrous acid diſſolves ſilver with great rapidity. When the ſtrong nitrous acid is diluted with an equal weight of water, it is capable of diſſolving about half its weight of ſilver. If the ſilver employed is quite pure, the ſolution is limpid like water; but as ſilver commonly contains a little copper, its ſolutions have uſually a blueiſh tinge.

 If

If the ſilver employed contains gold, in this caſe, as the nitrous acid is not capable of diſſolving the gold, it ſeparates from the ſilver in the form of blackiſh flocks. From this difference in the action of nitrous acid on ſilver and gold, it is ſucceſsfully uſed to ſeparate theſe metals from each other.

The ſolution of ſilver in the nitrous acid is extremely bitter and cauſtic, and has the property of changing the ſkin or hair to a black colour, or, if very much diluted, to a brown, and formerly, when the caprice of faſhion abhorred light hair as much as it at preſent admires it, was employed for that purpoſe. The colour is, however, very faint when the ſolution is firſt applied, and the production of colour ſeems in a great meaſure to depend on the action of light. Dr. Lewis mentions a remarkable phenomenon, which this ſolution preſents when added to chalk or any pure abſorbent earth. The chalk and ſolution are both at firſt quite white, and will continue ſo if kept in a dark place, but if expoſed to the light they ſoon become black; ſo that if a quantity of this mixture is put into a glaſs phial ſealed up, any marks or letters may be made to appear on it as if by magic. To effect this, the phial is covered with thick paper, in which the marks or letters are nicely cut, and it is then expoſed to the light, which, acting only through the apertures of the paper, produces the effect. When the ſtains are produced, aqua fortis, by re-diſſolving the ſilver, will make them diſappear again. It therefore ſeems, that the production of colour is owing to an imperfect reduction of the ſilver, and

that

that the action of light disengages oxygen from this compound in the same manner as it does from the pale nitrous acid, and from vegetables.

When this solution of silver is evaporated with a gentle heat, it may be made to afford crystals nearly resembling those of nitre. These, being melted in a crucible, are freed from water, and being poured into moulds of a convenient form, become the silver or *lunar* * caustic, or argentum nitratum of the pharmacopœia.

Silver is never given internally, and this is the only preparation of it made use of externally. The nitrous acid may be entirely separated from this compound by heat alone.

Silver, however, is most conveniently separated from its nitrous solution by immersing plates of copper in it. The copper is then dissolved, while the silver is deposited in its metallic state. This metal may be separated from gold by exposing the mixed metals to the action of nitrous acid, which dissolves the silver and leaves the gold, and the above method is used to obtain the silver from the acid.

To make the famous fulminating silver, which is so truly formidable in its effects, a small quantity of silver is dissolved in pale nitrous acid (or aqua fortis) from which it is precipitated by lime water. The

* A name taken from the whim of the alchemists, who called the metals by the names of the heavenly bodies: gold, Sol; silver, Luna; copper, Venus; iron, Mars (whence martial vitriol, &c.); lead, Saturn; tin, Jupiter; quicksilver, Mercury, &c.

calx or precipitate is to be dried by expofure to the air for three days. The inventor, M. Bertholet, fuppofes the action of light to have alfo fome influence in the fuccefs of the experiment*. The dried calx is then agitated in a folution of the cauftic volatile alkali, when it affumes the form of a black powder, which is left to dry in the open air. The fulminating filver then confifts of an union of the calx of filver with volatile alkali.

The effects of this preparation are tremendous, and infinitely exceed thofe of gunpowder, fulminating powder, or fulminating gold. It explodes with the flighteft agitation or friction. The falling of a few atoms of it from a moderate height produces a violent detonation, and a drop of water falling upon it has the fame effect. When it is once fully prepared, it muft not be touched or moved into any other veffel, but muft remain in that in which it was dried; and to make the experiment with tolerable fafety, not more than a grain of filver fhould be employed in the procefs. The caufe of thefe explofions has been already intimated in the chapter on ignition, and will be further illuftrated in treating of fulminating gold.

Though the nitrous acid diffolves filver with greater eafe, it has not fo ftrong an attraction for it as the muriatic or vitriolic acids. Either of thefe, dropped into the nitrous folution, feize the filver, and forming a compound not equally foluble produce a precipitation. The neutral falts, containing

* Journal de Phyfique for June 1788, p. 474.

vitriolic

vitriolic or muriatic acid, have the ſame effect. This difference of affinity between the acids and ſilver is the foundation of a proceſs for obtaining the nitrous acid in a ſtate of great purity. The ſolution of ſilver in nitrous acid is poured into the impure nitrous acid till no more precipitate is formed. The muriatic or vitriolic acids contained in the mixture are thus carried to the bottom by their union with the ſilver. The acid is then decanted and diſtilled to free it from the ſmall quantity of ſalt of ſilver which it may ſtill contain.

Notwithſtanding the muriatic acid has the ſtrongeſt affinity with ſilver of all the acids, it is nevertheleſs incapable of diſſolving it unleſs the metal is in a calcined ſtate, or itſelf ſuperoxygenated. The common method of effecting this union is to add to the ſolution of ſilver, in the nitrous acid, any ſaline ſubſtance which contains the muriatic acid; it is no matter to what the acid is joined, whether alkali, earth, or metal; it immediately ſeizes the ſilver, and leaves the other matter to unite with the nitrous acid. Common ſalt is generally uſed, and the white precipitate, which is immediately formed, has the appearance of a coagulum. The compound thus made is ſo inſoluble in water, that there cannot be a nicer teſt of the preſence of the muriatic acid, or common ſalt, in waters, than the nitrous ſolution of ſilver; for if the moſt minute quantity of either are preſent a precipitation is produced.

This compound has many other qualities beſides inſolubility in water. If we collect it, and waſh off the ſaline matter, it appears as a fine powder, and,

when heated to a ſufficient degree, melts into a ſubſtance of ſome tranſparency. From its tranſparency, flexibility, and ſoftneſs, it is called *luna cornea*, or *argentum corneum*, and from this ſeveral other compounds of metals with the muriatic acid have been called *cornea*. It may be cut into tranſparent veſſels reſembling glaſs.

Aqua regia, or the compound of nitrous and muriatic acids, acts ſtrongly on ſilver, but forms a precipitation in proportion as it ſeparates it from the maſs. This effect may be readily underſtood from what has already been obſerved. The nitrous acid diſſolves the ſilver, and the muriatic ſeizes it, and forms *luna cornea*, which is inſoluble. This proceſs may be uſed to ſeparate gold from ſilver; the gold is held diſſolved in the aqua regia, but the ſilver is precipitated.

After ſilver has been reduced to the calciform ſtate by ſolution in nitrous acid, and precipitation by alkalies, it is capable of ſolution in vinegar, and even in lemon juice; but theſe compounds have not been applied to any uſe.

To have ſilver perfectly pure we muſt uſe quickſilver, which, if poured into a ſolution of ſilver, is attracted by the acid, and precipitates an amalgam with the ſilver at the bottom of the veſſel. The quickſilver is eaſily ſeparated from the ſilver by heat alone. A curious phenomenon ariſes from this amalgam; a kind of cryſtallization takes place, which is formed by the union of the ſilver with the running mercury. The amalgam puts forth ſhoots, which

which afterwards put forth others, like the branches of a tree. The cryſtallization varies according to the conduct of the proceſs, and does not always anſwer, particularly if the mixture is ſhaken. It is called *arbor Dianæ*, or Diana's tree *. The method of making it moſt beautiful is very tedious, and would require the ſpace of a month.

This phenomenon ſeems to admit of explanation preciſely on the ſame principle as the branching of pure ſilver when paſſing from its fluid to its ſolid ſtate. The amalgam of ſilver and mercury is ſpecifically heavier than either of the metals in a ſeparate ſtate, and their union muſt conſequently be attended with contraction. The ſilver, therefore, being precipitated on the ſurface of the mercury, in proportion as the latter metal is diſſolved by its ſuperior attraction for the acid, the mercury becomes ſurrounded with a cruſt, the contraction of which forces out its fluid contents; the excreſcences thus produced being in their turn covered with a cruſt of amalgam, are again compreſſed, and produce ſmaller protuberances, and if the experiment is properly conducted, the brittle amalgam of the metals aſſumes a cryſtallized appearance, and the form of a thick buſh. In this experiment it is neceſſary that there ſhould be not only as much mercury as is ſufficient to precipitate the ſilver, but beſides this a quantity remaining in its fluid ſtate,

* Diana's tree, from the whim of the alchemiſts already noticed, who appropriated ſilver to the Moon or Diana, as ſtated in a preceding note.

to

to unite with the precipitated ſilver into an amalgam.

Sulphur has a remarkably ſtrong affinity with ſilver, and forms with it a compound which has the appearance and ſoftneſs of lead. This metal ſeems alſo capable of attracting ſulphur from antimony. But though ſilver has ſo ſtrong an attraction for ſulphur, gold has none, and this furniſhes a method of ſeparating theſe metals by fuſion.

With gold, ſilver forms a pale alloy, the green gold of the jewellers and gold beaters. This mixture, however, is not made without ſome difficulty, on account of the different ſpecific gravities of the two metals. It does not unite well with platina. It forms an alloy with iron, but the properties of it have not been well examined into. With lead it forms an alloy, which is much more fuſible than pure ſilver, and ſeems in all reſpects to be of an intermediate nature between theſe metals. Copper increaſes the hardneſs of ſilver, and renders it more ſonorous, without impairing its ductility or colour, when the copper does not exceed the twelfth part of the weight of ſilver employed. The ſtandard of ſilver coin is eleven ounces two pennyweights, troy, of ſilver, and eighteen pennyweights of copper.

The purity of ſilver cannot be accurately aſcertained without ſubmitting it to cupellation with lead, and its purity is calculated according to the weight it loſes in that proceſs. Silver is divided into twelve imaginary parts, called pennyweights. If it only loſes one twelfth part of its weight by cupellation, it contains eleven twelfths of pure ſilver;

ver, and is ſaid to be eleven pennyweights fine; if it loſes two twelfths, it is ten pennyweights fine, and ſo of other proportions. For greater accuracy, each pennyweight is ſuppoſed to be divided into twenty-four grains.

The covering of the ſurface of copper with ſilver, or plating, is performed in the following manner: ' Upon ſmall ingots of copper, plates of ſilver are bound with iron wire, generally allowing one ounce of ſilver to twelve ounces of copper. The ſurface of the plate of ſilver is not quite ſo large as that of the copper ingot. Upon the edges of the copper, which are not covered by the ſilver, a little borax is put, and by expoſing the whole to a ſtrong heat, the borax melts, and in melting contributes to melt that part of the ſilver to which it is contiguous, and to attach it in that melted ſtate to the copper. The ingot, with its ſilver plate, is then rolled under ſteel rollers, moved by a water wheel, till it is of a certain thickneſs; it is afterwards rolled by hand rollers to a greater or leſs extent, according to the uſe for which it is intended; the thinneſt is applied to the lining of drinking horns. An ounce of ſilver is often rolled out into a ſurface of about three ſquare feet, and its thickneſs is about the three thouſandth part of an inch; and hence we need not wonder at the ſilver being ſoon worn off from the ſharp angles of plated copper, when it is rolled to ſo great an extent.

' What is commonly called French plate is not to be confounded with the plated copper. In making

making French plate, copper, or, more commonly, brafs, is heated to a certain degree, and filver leaf is applied upon the heated metal, to which it adheres, by being rubbed with a proper burnifher*.'

* Watfon's Chemical Effays.

CHAP.

# CHAP. XXXIII.

## GOLD.

*General Properties of Gold.—Gold calcined by Electricity.—Extreme Ductility of this Metal.—Natural History of Gold.—Processes for separating Gold from other Substances.—Quartation.—The Touchstone.—Aqua Regia.—Reasons why the different Acids act on metallic Bodies.—Fulminating Gold.—Purple Powder of Cassius.—Golden Calf, how destroyed by Moses.—Union of Gold with other Metals.—Standard Gold Coin of different Countries.*

GOLD is the heavieſt of all the metals except platina, being between nineteen and twenty times the weight of water. When perfectly pure it is almoſt as ſoft as lead, and is neither elaſtic nor ſonorous. For its fuſion it requires rather more heat than ſilver, and when in fuſion has a blueiſh green colour, and its ſurface is always perfectly bright. The moſt intenſe heat cannot calcine it, and only contributes to render it more pure if it had any foulneſs. The powerful burning mirrors are ſaid to have volatilized it, and it has been driven up in fumes, in the metallic ſtate, by flame urged upon it by a ſtream of vital air. The electric fluid, however, when made to paſs in conſiderable quantities through gold leaf, incloſed between two plates of glaſs, converts it into a calx, which tinges the glaſs of a purple colour.

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The tenacity of gold is ſo great, that a wire one-tenth of an inch in diameter is capable of ſupporting five hundred pounds. Its malleability and ductility exceed thoſe of ſilver, and are ſo remarkable, that their limits could never be aſcertained with any conſiderable exactneſs. On gold lace the thickneſs of the gold has been computed to be leſs than the one hundred and thirty-four thouſandth part of an inch, and the degree of extenſibility has been carried ſtill farther. In ordinary gold-leaf, which is made by hammering plates of gold between ſkins, or animal membranes, a grain is made to cover fifty-ſix ſquare inches and a quarter. In this ſtate its ſurface is ſo great that it may be made to float in the air with the ſlighteſt agitation, and its thickneſs is not more than the two hundred and eighty-two thouſandth part of an inch.

Gold is produced by nature very plentifully. There is much of it in Brazil, in the Spaniſh Eaſt and Weſt Indies, on the coaſt of Africa, and in Upper Hungary, where the mines have remained unexhauſted for ten centuries. Peru and Mexico abound with gold in a variety of forms. It is met with in the ſands of rivers and mountains. Some rivers in France, as well as in this country, contain gold in their ſand. It is alſo found in the fiſſures of rocks, imbedded in hard ſtones. Pieces of gold of ſeveral ounces, and even pounds weight, are ſometimes found, but in general it is diffuſed in ſo ſmall portions, and through ſo large a quantity of ſand, that the trouble of extracting it is ſcarcely repaid by the gains. In all parts of the world, particularly in Europe, gold is moſt frequently found

in ſtrata of ſand, in which it ſeems to have been depoſited by water. Gold mines were once wrought in Scotland, and it appears upon record that forty-eight thouſand pounds ſterling of this gold was coined in the Scotch mint. It is now a general opinion among mineralogiſts, that there are ſcarcely any ſands entirely free from gold, and which, by accurate examination, cannot be made to afford more or leſs of that ſubſtance.

Conſidering that gold has no attraction for ſulphur, and very little for arſenic, which are the uſual mineralizers of metallic bodies, it is not ſurprizing that it ſhould be uſually found in a ſeparate and nearly pure ſtate. The metallic bodies, with which it is alloyed in a ſtate of nature, ſeldom conſtitute any conſiderable part of its weight; they are generally either ſilver, copper, or iron. Gold, however, is ſometimes mixed with martial pyrites, and is ſometimes contained in an ore, which is a mixture of lead, ſilver, and iron, mineralized by ſulphur. In theſe caſes the preſence of gold is not known by the appearance of the mineral, and can only be diſcovered by roaſting, and ſubſequent fuſion with ſuch matters as are capable of vitrifying the earthy and martial ſubſtances. The addition of lead is alſo uſeful, which unites with the gold, and carries it to the bottom of the maſs. The gold is eaſily obtained free from the lead by the proceſs of cupellation.

In order to ſeparate gold, when in its native ſtate, from the earthy and ſtony matters in which it is contained, the following proceſs is employed: When it

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is contained in ſand, the lighter particles of the latter are waſhed away by water, and the remaining matter, which may prove ſo heavy as not to be ſeparated from the gold without danger of loſing ſome of the precious metal, are amalgamized, by being ground with mercury, in the ſame manner as has been mentioned in the extraction of ſilver. If the gold is mixed with ſtones of conſiderable bulk, it is neceſſary that they ſhould be reduced to powder in order to render them ſufficiently light to be waſhed away. The mercury is alſo ſeparated from gold in the ſame way as from ſilver; as much as poſſible is ſeparated from it by preſſure in bags of leather, and the remainder by heat.

All the imperfect metals may be abſtracted from gold by cupellation; but in order to ſeparate ſilver from it, other proceſſes muſt be employed. The beſt of theſe is called quartation, becauſe the gold muſt not exceed the *fourth* part of the weight of the maſs ſubmitted to trial. The gold, therefore, muſt be firſt mixed with three times its weight of ſilver, the effect of which is, that the particles of gold are removed to ſuch a diſtance that they cannot protect the ſilver from being acted on. The maſs of gold and ſilver being then beaten out into thin plates to increaſe the ſurface, are expoſed to the action of aqua fortis, which diſſolves the ſilver, and leaves the gold in a ſpongy maſs; this is waſhed two or three times with aqua fortis, and then expoſed to heat in a muffle *, to recover its metallic

* A ſmall earthen oven made and ſold by the crucible manufacturers.

brightneſs.

brightneſs. When ſilver is thus ſeparated by aqua fortis, a minute portion of the ſilver is apt to adhere to the gold, and, therefore, when it is an object to have the gold perfectly pure, it is proper to ſubmit it to the action of aqua regia, which diſſolves the gold, and converts the ſilver into luna cornea, which is precipitated to the bottom of the veſſel. When it is intended to ſeparate ſilver by aqua regia, the proportions of the metals muſt be reverſed, and as the gold is to be diſſolved, it muſt be three times the weight of the ſilver.

In this way gold may be obtained quite pure; but the goldſmiths find a difficulty in obtaining it perfectly ductile. To have it ſoft and tough it muſt be melted with a ſtrong heat, and afterwards cooled very ſlowly.

In applying ſaline ſubſtances to gold, it is found that none of the acids, ſeparately employed, either in a fluid form or in that of hot vapours, produce the leaſt effect on it in its metallic ſtate. Upon this depends the trial of gold by the lapis lydius, or touchſtone, which is of a dark colour and pretty fine grain, but when poliſhed has ſufficient roughneſs, ſo that when the metal is rubbed over it a mark is left, which mark will be affected by any of the common acids, aqua fortis for inſtance, in proportion to the impurities the metal contains, but not at all if the gold is perfectly pure.

Goldſmiths uſe likewiſe two ſets of needles, one for ſilver and the other for gold, when they want to examine the fineneſs of different parcels. The ſets of needles for gold are alloyed with different proportions

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of copper; one is made with twenty-three parts of gold to one of copper, another with twenty-two parts of gold to one of copper, and ſo in proportion. When they have a piece of gold to be tried, they firſt examine its colour to determine what quantity of alloy it contains. To know this the better, they mark the touchſtone with it, and then make another mark with the needle, which they think to be of nearly ſimilar purity. Thus they compare them; and after this, to be certain that the metal is gold, they apply to the mark on the ſtone a drop of aqua fortis. If it is copper tinged with zinc, or any other imitation of gold, the aqua fortis immediately diſſolves it. If it contains gold and ſome other metal, it diſſolves the other metal, and leaves the gold.

The only ſaline fluid which diſſolves gold in its metallic ſtate is aqua regia, or a mixture of the nitrous and muriatic acids. It is prepared various ways: 1ſt, By mixing the two acids in their pure ſtate. 2dly, By adding common ſalt, or ſal ammoniac, to aqua fortis, and then diſtilling the mixture. A part of the nitrous acid decompoſes the muriatic ſalt, and detaches the muriatic acid, which riſes with the remainder of the nitrous acid, and thus an aqua regia is produced. 3dly, By mixing a ſolution of alum with nitre and common ſalt, in which caſe the vitriolic acid of the alum diſengages the nitrous and muriatic acids by its ſuperior attraction for their baſes.

It is uſual to make aqua regia by diſſolving ſal ammoniac in about four times its weight of ſtrong nitrous

nitrous acid; but the results of experiments or operations vary considerably according to the proportion of the ingredients made use of.

The theory of the operation of this compound acid does not seem difficult. In the course of this work it has been more than once remarked, that the easy solution of metallic matters in acids does not depend merely on the degree of attraction which exists between the metal and the acid, but also on the ease with which the acid parts with oxygen to calcine the metal. From this cause it happens, that the nitrous acid, which has much less affinity with metallic matters than the vitriolic or muriatic, dissolves them more readily than either of these. Aqua regia, however, consists of the acid which has the strongest attraction for metallic bodies, and also of that which most easily parts with oxygen, and the union of these powers produces the effect of solution. That this is the true explanation of the solution of gold in aqua regia appears from several circumstances; for gold, previously reduced to the state of calx, that is, furnished already with a quantity of oxygen, is easily dissolved by muriatic acid, and gold, in its metallic state, is dissolved by the oxygenated or aerated muriatic acid, and forms with it the same salt which is usually obtained by the mixed acid, or aqua regia. The muriatic acid, therefore, is the true solvent of gold, and the addition of nitrous acid has no other effect than that of furnishing oxygen, since the same effect follows when the necessary quantity of oxygen is previously added either to the gold or the

muriatic acid. Gold, precipitated from aqua regia by alkalies, and thus reduced to the calciform state, is soluble even in the vitriolic and nitrous acids.

The addition of water to the vitriolic acid enables it to dissolve iron exactly on the same principle that the addition of nitrous acid to the muriatic enables the latter to dissolve gold. The concentrated vitriolic acid has no action on iron without the assistance of heat; but by a proper addition of water the process goes on, in the ordinary temperature of the atmosphere, with considerable rapidity. The water furnishes oxygen to the iron, and its other component part, hydrogen, is set at liberty; and that the nitrous acid, in the aqua regia, answers the purpose of furnishing oxygen to the gold, is proved by the disengagement of nitrous gas.

The solution of gold in aqua regia, when first made, is always yellow, considerably caustic, corrodes animal matters, and tinges them of a deep purple colour. When applied to the surface of marble, it tinges it of a violet colour. This colour is produced by a precipitation of the gold, in consequence of the superior attraction of the calcareous earth for the acid.

The solution of gold may be made, by cautious evaporation, to afford crystals of a beautiful topaz or yellow colour. Gold may be in some measure volatilized by repeatedly distilling it with aqua regia; some of the gold rises with the acid into the neck of the retort in the form of long slender brown crystals.

Gold is precipitated from its solution by a great variety of substances, but its appearances are very various, according to the nature of the matter employed. Lime and magnesia precipitate gold in the form of a yellowish powder, and the fixed alkalies have the same effect. Volatile alkali produces a more quick and copious precipitation, and forms the remarkable compound, known by the name of aurum fulminans, the nature of which has been already intimated in a note under the head of ignition. I shall in this place, however, add a few observations, which may tend still further to illustrate its nature. In the first place, it appears that the fulminating gold is a compound of about three parts of that metal with one of volatile alkali. Secondly, Fulminating gold, exposed to such a heat as is sufficient to separate the volatile alkali, without setting fire to the compound, loses its fulminating property. The same effect is produced by submitting the aurum fulminans to the action of concentrated vitriolic acid, melted sulphur, æther, or any substance capable of abstracting the volatile alkali by superior affinity. Thirdly, When a few grains of aurum fulminans are detonated in copper tubes, the extremity of which is plunged beneath the mercury of the pneumato-chemical apparatus, azote is disengaged, a few drops of water are produced, and the gold is restored to its metallic appearance. M. Berthollet, the inventor of this experiment, concludes, that the volatile alkali is decomposed, and that while one of its component parts, hydrogen, unites with the oxygen of the calx of gold, and

forms water, its other component part, azote, escapes in the form of gas. The readiness with which fulminating gold explodes seems to depend on the tendency which the hydrogen of the alkali has to unite with the oxygen of the metallic calx, which tendency the weak attraction of the gold for the oxygen on the one hand, and the azote for hydrogen on the other, are scarcely sufficient to counteract. Whenever the balance of power among these ingredients is disturbed, which happens from a moderate increase of heat, or violent friction, the hydrogen and oxygen unite and form water, the gold is reduced, and the azote escapes in the form of gas, occasioning a violent explosion.

When gold is newly precipitated, Margraff informs us, that it may be re-dissolved by the volatile alkali, or, much more readily, by the Prussian alkali. Alkaline salts precipitate gold in the form of a calx, but inflammable substances precipitate it in the metallic form. The most singular effect of inflammable substances upon the solution of gold is that of the vitriolic æther, though it does not entirely separate the gold from the acid. If into a phial of distilled water a single drop of the solution of gold is introduced, the water will become of a fine yellow colour; add to this a quantity of vitriolic æther, which will float uppermost, and remain colourless, no sensible change being produced; by shaking the mixture, however, for some time, and then allowing it to rest, the yellow colour in the lowest part of the phial will leave the water, and rise up into the æther.

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By repeated agitation, in a little time the æther will draw up into it the whole of the gold, so as to leave the liquor at bottom perfectly colourless. It would be erroneous to conclude from this experiment, that æther is a solvent of gold; it does not dissolve it, but attracts the solution merely by its affinity for acids. Though the æther acts primarily on the acid, it at length separates the oxygen from the calcined gold, and precipitates it in its metallic state. All the subtile aromatic oils have a similar effect, but do not act so readily as æther.

As these inflammable fluids have no action on the solutions of other metals, this process may be used as a means of refining gold; for the acid containing gold is imbibed by the inflammable fluid, while that part of it which is combined with any other metal remains behind.

Almost all metallic substances precipitate gold from its solution in aqua regia. Mercury and copper separate it in its shining metallic form; lead, iron, and silver, precipitate it of a deep and dull purple colour. A plate of tin, plunged in a solution of gold, separates the perfect metal in the form of a deep violet powder, called purple powder of Cassius, which is used in painting, in enamel, and in porcelain. This powder consists of the calces of gold and tin in combination, and is capable of communicating a fine purple colour to glass. The solution of green vitriol precipitates no other metal but gold, and the gold proves of uncommon purity, and of a very deep colour. Gold in its metallic state is incapable of uniting with sulphur alone, but if a piece

of gold is dropped into a solution of hepar sulphuris, especially if the latter is prepared with equal parts of sulphur and alkali, the gold dissolves with some ebullition, and forms a mass, which dissolves in water like the combination of alkali and crude antimony.

Stahl supposes that this process was used by Moses to render the golden calf, adored by the Israelites, soluble in water.

But though gold will not unite with sulphur, it may be purified by means of it, the sulphur uniting with the metals with which it is alloyed. With this view it is usual to heat the gold with crude antimony, in which state the sulphur is more fixed than when applied in a separate state. In this process, however, the gold combines with a portion of antimony, which must be afterwards driven off by heat.

There are scarcely any metals with which gold will not unite. When boiled a short time with mercury, it forms an amalgam which is gritty and rigid at the first, but which becomes by grinding more soft and tender; this is often made use of for gilding the surface of silver and copper, as was more particularly mentioned when treating of the latter metal.

Gold readily unites with zinc, and produces a mixed metal, whiter than might be expected from the quantity of zinc which is employed; this alloy, made with equal parts of the two metals, is remarkably splendid, is of a fine grain, and is not liable to tarnish: on account of these properties it has been recommended in constructing the mirrors of telescopes.

All the metals, except ſilver and copper, take away the ductility of gold, but none more remarkably than tin, a grain of which added to a thouſand of gold is ſaid to deprive it entirely of ductility. Copper is commonly uſed to alloy gold, as ſilver renders it very pale. Copper rather heightens the colour of gold, but inclines it to red.

Goldſmiths denote the fineneſs of gold by the word carrat. It is ſuppoſed to be divided into twenty-four parts, called carrats; and gold, which is quite free from alloy, is ſaid to be twenty-four carrats fine; that which contains one twenty-fourth of alloy is called gold of twenty-three carrats; that which contains two twenty-fourths, of twenty-two carrats, and ſo on. In England, the ſtandard of gold coin is twenty-two carrats fine gold and two carrats of alloy, which latter is half ſilver and half copper. The French, Spaniſh, and Flemiſh gold are nearly of the ſame fineneſs.

## Chap. XXXIV.

### PLATINA.

*Natural History of this curious Metal.—Its Properties.—The most ponderous Body in Nature.—Its Hardness and Infusibility.—Soluble only in Aqua Regia and oxygenated muriatic Acid.—Its Union with other Metals.—Crucibles formed of it.—Might be applied to various Uses which no other Metal can answer.*

IN the beginning of the year 1749, the first specimen of this metal was brought into England from Jamaica. It was said to have been originally brought from the Spanish West Indies, and it is still almost exclusively found in the gold mines of Spanish America. It is brought over in the form of small smooth grains, irregularly figured, with round edges, and is often mixed with ferrugineous sand and grains of quartz or crystal. The grains of platina are whiter than iron, but less so than silver, and their flat form is probably owing to the pressure they undergo in the mills in which the gold is amalgamated.

In confirmation of this opinion, small particles of gold and mercury are usually found mixed with the grains of platina. In the state in which they are brought over, they fall short of the weight of gold, but by purification, which is performed by washing with the muriatic acid, and by exposing them for a long time to the heat of the most violent furnaces, which, however, are said to be insufficient to melt

them *, they exceed it. The ſpecific gravity of gold is about nineteen times that of water, whereas platina, which ſtill contains ſo much iron as to render it magnetical, is upwards of twenty-one times the weight of that fluid. It is extremely difficult to free platina from the laſt portions of iron, but ſome minute particles, which have been fuſed by the focus of a burning glaſs, and ſo far purified as not to be attracted by the magnet, appear to exceed twenty-two times the weight of water.

Platina is, perhaps, the moſt perfect of all the metals. As it ſo conſiderably exceeds even gold in weight, it is therefore to be conſidered as the moſt ponderous body in nature.

It has ſeveral properties in common with the moſt uſeful of metals, iron. In hardneſs it approaches to that metal in the ſtate of ſteel; and in infuſibility it exceeds it even in the ſtate of ſoft iron; it alſo conſiderably reſembles iron in appearance, and it is the only metal, beſides iron, which has the property of welding.

Platina reſembles gold in being ſoluble only in aqua regia, and it even requires a larger quantity of that compound acid for its ſolution than gold. The ſolution is of a deep yellow or reddiſh colour. The proportions of acids beſt adapted to the ſolution of platina are, equal parts of the nitrous and muriatic acids; but the ſolution does not then take place with rapidity. This compound is very cor-

* This is the opinion of the generality of mineralogiſts; but my friend and chemical preceptor, Dr. Higgins, aſſured me, he had melted platina in his furnace.

roſive,

rosive, and tinges animal substances of a blackish brown colour.

The vegetable alkali added to this solution only occasions the precipitation of a part of the metal in the form of a sparkling powder, which is soluble in a large quantity of water. A very remarkable circumstance is, that the fossil alkali does not produce any precipitation, unless added in very considerable quantity. Common sal ammoniac, applied to the solution of platina, produces a precipitation like the fixed vegetable and volatile alkalies. It separates a part of the metal in a sparkling red powder, and a part remains dissolved, which it cannot separate; but if vegetable alkali is added after the sal ammoniac, it precipitates the rest of the platina; and on the contrary, sal ammoniac, added to the solution containing the remainder, which the fixed alkali could not separate, precipitates it, so that by adding both the vegetable alkali and sal ammoniac, the whole of the platina is separated. Platina, like gold, is also soluble by the oxygenated muriatic acid.

The subtile inflammable substances, as spirits of wine and aromatic oils, do not produce any separation from the solution of platina in aqua regia, as they do from that of gold. Tin precipitates it, but the precipitation is not purple like that of gold. Most of the metals precipitate platina, but it does not in general fall down in the metallic state. The precipitation of platina, from its solution by sal ammoniac, affords a method of separating this metal from the gold which is mixed with it, as the gold

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is not ſeparated by the addition of that ſalt; if, on the contrary, we wiſh to precipitate the gold, and leave the platina in ſolution, this may be effected by ſal martis.

The precipitates of platina may be reduced to a metallic button, by heating them with the common fluxes; but theſe cannot be rendered malleable unleſs they are completely fuſed, which can ſcarcely be effected, unleſs with the heat of the moſt powerful burning glaſſes.

A mixture of copper with platina forms a metallic body of intermediate colour and great denſity, ſo that it receives a very fine poliſh. A mixture of three or four parts of copper to one of platina poſſeſſed all the above properties in great perfection, and was not tarniſhed in the air in the ſpace of ten years. With iron it alſo produces a compound of great denſity, which is hard, ſtrong, and tough, and admits of a good poliſh. Moſt metals increaſe the fuſibility of platina ſo much, that it may be melted in ordinary furnaces.

Gold is greatly injured in colour by a mixture of platina, and becomes of the colour of bell metal by the addition of no more than one twenty-fourth part, though half that quantity produces little change.

Platina with biſmuth and tin forms alloys, which are brittle, but eaſily fuſed. Platina and lead unite very well by fuſion, but the ductility of the lead is deſtroyed, and the compound quickly tarniſhes on expoſure to air. Platina partly deſtroys the ductility

lity of ſilver, augments its hardneſs, and impairs its colour.

Platina completely reſiſts the action of mercury, with which it ſhews no diſpoſition to unite. On this account it does not mix itſelf with the gold, which is extracted from the ſubſtances with which it is mixed by amalgamation.

From the extreme infuſibility of platina, it is excellently fitted to contain other matters, which it is intended to ſubmit to a violent heat. M. Achard ſucceeded in making crucibles of platina, by fuſing equal parts of platina, white arſenic, and vegetable alkali. This matter, when cooled, was reduced to a powder, and rammed into a mould. A ſtrong heat, quickly raiſed, and continued for ſome time, fuſed the maſs, and after diſſipating the arſenic and alkali, left the platina in the deſired form.

Platina, when thoroughly purified, by coction in the muriatic acid and precipitation from aqua regia, may be fuſed into a maſs nearly as malleable as ſoft iron. This property, united to thoſe of reſiſting acids, its great infuſibility, and welding, ſeem to render platina applicable to purpoſes which no other metal is capable of anſwering.

CHAP.

# CHAP. XXXV.

## OF INFLAMMABLE SUBSTANCES IN GENERAL.

*Ignition and Combustion defined.—Acids formed by the Combustion of inflammable Substances.—Flame, how produced.—The Object of the present Inquiry limited.—What Substances are commonly termed inflammable.*

THE difference between ignition and combustion consists in this:—All bodies which can support a certain degree of heat, without the destruction of their texture, emit light, and this is called ignition; but combustion or inflammation is a property which belongs to such bodies only as are capable, when placed in proper circumstances, of augmenting their own temperature. Simple ignition produces no permanent change in bodies, but combustion entirely alters the properties of such as have undergone that process. From being mild and nearly insoluble in water, they become acrid, pungent, and extremely soluble, and are converted into acids, which differ according to the substance, by the inflammation of which they were formed. The terms combustible substance and acidifiable basis are, therefore, in the French nomenclature, synonymous.

In the elementary part of this work it has already been remarked, that inflammation is the disengagement of the matter of heat or caloric contained in vital

vital air or oxygenous gas, in consequence of the basis of this gas becoming combined with other bodies. All bodies, therefore, which are capable of decomposing vital air, change a quantity of latent heat into sensible heat, and are said to be inflammable from the light and heat which *seem* to proceed from them, but which, in fact, are derived from the oxygenous gas, which is one of the component parts of the atmosphere.

The necessity of the presence of air to combustion is strongly maintained by M. Lavoisier, and an experiment related by him (to the latter part of which I feel some reluctance to give an unqualified assent) seems, indeed, to prove it to be essential in all cases. He successively placed a quantity of phosphorus, of sulphur, and of gunpowder, under the receiver of an air-pump, making as perfect a vacuum as the machine would admit. He then threw the focus of a lens of eight inches diameter on the different substances, which were not at all ignited, only bubbled up, and at length sublimed. The gunpowder was decomposed, the sulphur of it only subliming, and it neither took fire nor exploded.

In ordinary language, no bodies are said to be inflammable but such as burn easily, or which, in other words, are capable of decomposing vital air in the diluted state in which it exists in the atmosphere. In a more strict sense, however, the property of inflammability belongs to other bodies, though they possess it in a less eminent degree; as to zinc, which, when made extremely hot, burns with a dazzling white light, and to iron, which,

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when heated to a proper degree, burns in pure oxygenous gas. The oxygenation which all metals, except the perfect, undergo from the conjoined operation of heat and air, are also to be considered as cases of slow combustion. In short, all substances may be said to be inflammable which are capable, in any circumstances, of decomposing vital air, or which have a stronger attraction for the base of that air than that base has for caloric or heat.

In all instances of inflammation a certain degree of heat is necessary to begin the process. Different inflammable substances require different degrees of heat for this purpose. Phosphorus is fully inflamed at the heat of 86 degrees of Fahrenheit, but undergoes a more gradual combustion at a much lower temperature. Sulphur requires much more heat than phosphorus, and charcoal still more than sulphur. There are some substances in nature which are so combustible, or have so strong an attraction for oxygen, as never to have been found uncombined with that principle; of this kind are the unknown bases of the boracic, fluoric, and muriatic acids.

Though an acid is always formed by the combustion of every inflammable substance, this fact was never attended to, or at least never properly apprehended, till within these few years. In ordinary cases, indeed, this circumstance was likely to pass unobserved; for the acid produced by the inflammation of charcoal, which is the essential ingredient in all kinds of fuel, is the carbonic acid

gas, or fixed air, which escapes without leaving any traces. In the combustion of sulphur also, the acid flies off in fumes, unless collected by a particular process, which was described in treating of the sulphuric or vitriolic acid. The phosphoric acid, however, is a concrete body, and therefore cannot easily be overlooked. When inflammable bodies are united with oxygen they become acids, and having no longer sufficient attraction for oxygen to decompose vital air, they lose their inflammability. According to the old chemical doctrine, the heat and light afforded by inflammable substances were supposed to derive their origin from the disengagement of phlogiston; but, according to the doctrine of M. Lavoisier, the vital air of the atmosphere is the repository of light and heat, from which all artificial supplies are derived, by means of inflammable substances.

There is one striking difference among inflammable substances, which is, that some burn with and some without flame. Of the former kind are oils, spirits of wine, and most others; to the latter kind belong the different species of charcoal, and such of the metals as are inflammable. The cause of this difference is, that some inflammable bodies afford an inflammable vapour, the burning of which produces flame; others are entirely fixed, and produce no such vapour. The vapour, however, as it rises is not wholly consumed; the reason of which is, that the air does not find access to the center of the column of vapour. Flame is a hollow cone surrounding

rounding a solid cone of vapour. In large flames, the surface on which the air acts is less in proportion to the quantity of vapour than in small flames; hence the quantity of smoke and soot produced by small flames is proportionably less than that produced by large; for smoke and soot are only that part of the vapour which is unconsumed. Upon this principle it happens that more light is afforded by candles with a small wick, in proportion to the quantity of inflammable matter consumed, than by those with a large wick. The same end is answered by extending the wick in the form of a ring, and leaving room for a current of air in the middle, as is done in the patent lamps*.

In treating of inflammable substances it will be necessary to confine the inquiry to those which possess this property in a more remarkable degree. I shall, therefore, first treat of the simple inflammable substances, phosphorus, sulphur, and coal, or the carbon of the French philosophers. Hydrogen, or inflammable air, has already been described under the head of elastic or aeriform fluids. With respect to the compound inflammable substances, such as oils, resins, fat, &c. it will be found that they consist of different proportions

* This fact was previously explained in the chapter on ignition, in the second book. The inflammable part of the vapour is so completely consumed in Argand's lamps, that if an alembic is fixed to the top of the lamp, the matter condensed is altogether water.

and ſtates of combination, of carbon, hydrogen, and oxygen. The inflammable matter of charcoal and coke conſiſts of carbon only; pitcoal and wood, in their crude ſtate, contain alſo ſome hydrogen, which is driven off, together with water and oil, in the proceſs of charring.

# CHAP. XXXVI.

## PHOSPHORUS.

*Phosphorus of Kunkel.—Light from putrescent Substances.—Curious Facts.—Light from the Sea Water, &c.—Bolognian Stone.—Baldwin's Phosphorus.—Phosphorus of Homberg.—Pyrophori.*

PHOSPHORUS* is a simple combustible substance, which was unknown to chemists till 1667, when it was discovered by Brandt, a German chemist, who kept the process a secret; soon after Kunkel found out Brandt's method of preparation, and made it public. It has ever since been known by the name of Kunkel's phosphorus. The appearance of phosphorus is that of a transparent substance, of a colour inclining to yellow, like clear horn; it is specifically heavier than water, is tough, and cuts like bees' wax, and like it melts with a gentle heat into a transparent fluid. With this heat it may be melted in water; but if the same degree of heat is applied in the open air, it melts, takes fire, and burns, producing a bright white flame with intense heat. Phosphorus should be handled with great caution, as should any of it adhere to the skin, or get under the nails, the heat of the human body is sufficient to inflame it. The process for obtaining phosphorus from bones was described in treating of the phosphoric acid.

* Derived from the Greek—"A substance affording light."

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When a quantity of phosphorus is burnt in small pieces under a bell, the phosphoric acid attaches itself to the internal surface of the bell, in the form of a downy mass. This concrete acid has so strong an attraction for water as to imbibe it from the atmosphere with astonishing rapidity, till it is converted into a liquid considerably more dense, and of greater specific gravity than water.

From the experiments detailed in M. Lavoisier's elementary work on chemistry, it appears that one pound of phosphorus requires one pound eight ounces of oxygen gas for its combustion, and that two pounds eight ounces of concrete phosphoric acid are produced.

The phosphoric acid may be obtained by three other processes besides this. If phosphorus is melted in hot water, and a stream of vital air passed through it, it becomes oxygenated. The same thing happens by plunging it in nitrous acid, from which it abstracts the oxygen. It may be also acidified by simple exposure to the atmosphere, which ought not at the time to exceed the temperature of sixty degrees, from the danger of inflammation; in this situation, by a gradual combustion, it attracts the oxygen of the atmosphere, and becomes converted into an acid.

The caustic fixed alkalies dissolve phosphorus by the assistance of heat. During this combination a fetid gas is disengaged, which has the singular property of exploding as soon as it comes in contact with atmospherical air, and still more rapidly by contact with vital air.

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The phosphoric acid forms peculiar salts with the alkalies and some of the earths, and has the property of corroding glass. With the mineral alkali it forms a salt, the taste of which is less unpleasant than that of other neutral salts, and which is well calculated to answer the purposes for which neutral salts are used in medicine. The phosphoric acid acts only on a small number of metallic substances, but readily dissolves, in its fluid state, iron, zinc, and copper, with which it forms salts not crystallizable.

Phosphorus seems to be almost universal in the animal kingdom, and is also found in some minerals, and in a very minute proportion in most vegetables. The bones of animals are a true phosphat of lime, or an earthy salt composed of phosphoric acid and calcareous earth. The urine also contains a considerable quantity of phosphoric acid, chiefly combined with volatile alkali, but partly also with calcareous earth. This compound salt, afforded by the evaporation of urine, was formerly known by the names of essential salt of urine, or microcosmic salt. Brandt, Kunkel, and Margraff, and all chemists, till lately, prepared their phosphorus from that substance, but it is now almost entirely obtained from bones, which afford it more plentifully and with less trouble. Phosphorus does not yet seem to have been applied to any important uses.

From the remarkable ease with which phosphorus is inflamed, several experiments may be exhibited by means of it, which appear like the effects of magic to persons unacquainted with the nature of this substance. Thus, for example, if the outside

of a bottle is rubbed with phosphorus, and then surrounded with tow, and hot water poured into it, the phosphorus takes fire, and communicates the inflammation to the tow. If a stick of phosphorus is used to write on a piece of paper, or on a wall, a quantity of phosphorus is abraded, and, undergoing a slow combustion, renders the strokes visible in the dark, while in the light they can only be perceived to exhale a whitish vapour.

A fluid called liquid phosphorus is prepared by digesting some phosphorus in the heat afforded by horse dung for two days, in oil of cloves, oil of turpentine, or any similar substance. After dissolution, the oil will be so impregrated with it, that when the phial is opened, it will appear luminous. Any thing moistened with this fluid will in the dark seem to be on fire.

Many natural phenomena, which in the ages of superstition served to astonish and affright mankind, have received a satisfactory solution from the discovery of the phosphorus of Kunkel. We learn from Fabricius ab aquapendente, that three young men at Padua, having bought a lamb, and eaten part of it on Easter Day, 1592, several pieces of the remainder, which were kept till the day following, shone like so many candles when casually viewed in the dark. It appears by his account, that the astonishment of the whole city was excited by this phenomenon, and a part of the flesh was sent to him, who was professor of anatomy, to be examined by him. He observed, that those parts which were soft to the touch and transparent in candle

candle-light were the most resplendent. A philosopher of not less note, has furnished us with a very pompous account of a similar phenomenon, which occurred at Montpelier in 1641. A poor old woman had bought a piece of flesh in the market, intending to make use of it the day following; but happening not to sleep well that night, and her pantry being adjoining to her bed, she observed that a quantity of light proceeded from the meat, so as to illuminate almost the whole place where it hung. We may easily judge of the terror and astonishment of the poor woman herself, since we find that a part of the flesh was carried, as a very extraordinary curiosity, to Henry Duke of Conde, who viewed it with the utmost surprize for several hours. The light was as if gems were scattered over the surface, and continued till the flesh began to putrify, when it vanished, which it was believed to do in the form of a cross.

The attention of a more philosophic age was directed to experiments to ascertain the cause of this light. Mr. Boyle found, that the light of rotten wood was extinguished in vacuo, and revived again by the admission of air, even after a long continuance in vacuo. The extinction of the light was not so complete immediately on exhausting the receiver, as some little time afterwards. The wood was not much affected by condensed air; but the light of a shining fish, when put into the condensing engine, was rendered more vivid by that means. As air is therefore necessary to combustion, these experiments clearly indicate, that this light is the effect of a slow combustion, or something analogous to it;

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and, indeed, the experiments upon the phoſphorus of Kunkel have ſince placed this matter beyond a doubt. The combuſtion, however, in theſe caſes, is ſo very ſlow, that no change of air appeared neceſſary for the maintenance of this light, for it continued for a long time, even though the wood was confined within a glaſs hermetically ſealed.

To explain the cauſe of this combuſtion it is only neceſſary to repeat what has been juſt ſtated, that there exiſts in every animal body, and in moſt vegetables, a certain quantity of phoſphorus. This principle, we have ſeen, is extremely active, and has the ſtrongeſt tendency to unite with the pure part of our common air. During that ſeparation, therefore, of the parts of bodies, which takes place in an incipient putrefaction, theſe phoſphoric particles are detached from thoſe with which they are combined, and by the action of the air, a degree of combuſtion takes place, but ſo extremely faint, that light only is produced, without the leaſt appearance of ſenſible heat.

This ſhort explanation of the cauſe will, I flatter myſelf, correſpond with moſt of the phenomena of this kind noticed by philoſophers. Mr. Boyle found that the light of rotten wood was in moſt reſpects analogous to that of putreſcent ſubſtances. The light of the former, however, differed in ſome reſpects; it was preſently quenched with water, ſpirit of wine, and a variety of other fluids; but the light of ſome ſhining veal was not entirely quenched by water, though its virtue was inſtantly deſtroyed

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by spirit of wine*. The same philosopher was sometimes disappointed in his experiments on shining fishes; particularly he observed, that they failed to become luminous in cold and frosty weather, which is exactly agreeable to the nature of phosphorus, since its combustion is exactly in proportion to the heat which is applied to it. He remarks also in another place, that the light of shining wood was completely extinguished by extreme cold.

Some bodies have a much greater tendency to produce this light than others. A foreign philosopher remarked, that on opening a sea polypus it was so luminous as to startle most of the persons who saw it; the nails and the fingers of those who touched it became luminous also. The light of the glow worm, and other luminous insects, must depend upon some slimy or fluid matter which they emit, and which has this tendency to shine. There is a remarkable shell-fish, called *pholes*, which forms for itself holes in different kinds of stone. This fish illuminates the mouth of the person who eats it; and it is remarked, that contrary to the nature of other fish, which give light when they tend to putrescence, this is more luminous the fresher it is, and when dried its light will revive on being moistened either with salt water or fresh; brandy, however, immediately extinguishes it†.

The luminous appearance of the sea in the night time cannot have escaped the observation of any

* *Priest. Op.* 565. † Ibid. 567.

person

person in the least conversant with that element. The light occasioned by the dashing of oars, or by the motion of the waves by night, is extremely beautiful. Father Bourzes, in his voyage to the Indies in 1704, remarked particularly the luminous appearance of the sea. The light was sometimes so great, that he could easily read the title of a book by it, though nine or ten feet from the surface of the water. Sometimes he could easily distinguish, in the wake of the ship, the particles which were not luminous from those that were. The luminous particles also appeared of different forms; some appeared like points of light, others like stars; some of them resembled globes of a line or two diameter, and some appeared as large even as a man's head; they assumed square and triangular as well as globular forms, and not only the wake of the ship, but fishes in swimming, produced these luminous appearances. All these phenomena he attributes, and rightly, to the fat or putrescent state of the water, and observed, that when the wake of the ship was brightest, the water was most clammy and glutinous. In some parts of the sea, he saw a substance like yellow and red dust, and the sailors told him it was the spawn of whales which produced all these appearances*. Later experiments have proved, that the luminous appearance of the sea entirely proceeds from the putrescent parts of marine animals†.

* *Priest. Op.* 572. † Ibid. 576.

Human

Human bodies, as well as thofe of other animals, emit light juft when they begin to putrify; and the walls and roofs of places in which dead bodies have often been expofed have been obferved to have a flimy matter depofited on them, which was luminous in the dark. The lights which are fometimes feen in burial grounds undoubtedly proceed from this caufe alone*. Similar appearances have been obferved about the beds of fick perfons, probably in putrid difeafes: one of thefe was obferved about the body and the bed of a fick woman at Milan, which fled from the hand that approached it, but was at length difperfed by a ftream of air. It is well known that the fweat often contains a confiderable quantity of phofphoric matter †.

Certain ftony matters are called phofphoric; but do not in fact contain a particle of that fubftance. The moft remarkable ftone of this kind has been already noticed, I mean the *Bolognian ftone*, fo called from the place where it is ufually found. Margraff fays, that the Bolognian ftone is foft, friable, heavy, cryftallized, and incapable of effervefcing with acids, till it has been calcined in contact with fuel, and with a free accefs of air. Thefe qualities have induced him to clafs it among the heavy fufible fpars, all of which are capable of being rendered phofphorefcent. After analyzing thefe fubftances, he concludes, that they all contain vitriolic acid combined with calcareous earth, and that they are of courfe felenites. In order to make thefe ftones

* *Prieft. Op.* 576. † Ibid. 587.

phofpho-

phosphorescent, they must be heated red hot, and afterwards reduced to powder. This is to be made into a paste with gummy matter, and to be cut into cakes as thin as a knife. After these cakes have been heated in contact with charcoal, they are fit for use. What is called the phosphorus of Baldwin is a combination of chalk with nitrous acid; and the phosphorus of Homberg is a combination of quick lime with muriatic acid. All these substances have the property of shining in the dark for some minutes, after having been exposed to the light of the sun, or, according to Margraff, after having been simply heated. Most substances, after having been held in a bright light, emit some faint light on being suddenly removed into a very dark place, but the light afforded by the substances above described is so remarkable as to have attracted particular attention.

Bolognian stone can be illuminated by the light of a candle, but not by the light of the moon, or of another phosphorus. When one part of it is illuminated, it is not communicated to another. Two seconds will give it all the light it is capable of receiving, but one second will imperfectly illuminate it. Some specimens will continue visible for thirty minutes; but in general the light is not vivid for more than four minutes.

Father Beccaria, having inclosed some pieces of extraordinary good solar phosphorus in tubes, into which the light was admitted through glass, asserts, that the phosphorus was of that colour only which it imbibed. All these phosphori will

will loſe their virtue by being long expoſed to open day. Some of them will preſerve their beauty a long time though plunged in water, which in the end, however, deſtroys them; ſome of them will ſhine with peculiar ſplendor, while diſſolving in warm water, which is partly to be attributed to the heat they imbibe in this proceſs.

The ſubſtances known by the name of pyrophori, which ſpontaneouſly take fire when expoſed to the air, are variouſly prepared. A pyrophorus may be very eaſily made, by mixing alum or any vitriolic ſalt with charcoal, or any matter containing charcoal, and keeping them in a red heat for an hour, the air being excluded; this operation may be performed in the bowl of a tobacco pipe. The pyrophori, when made, muſt be very carefully kept from the air; for if the veſſel in which they are contained ſhould be accidentally opened or broken, there is danger of their ſetting fire to any thing with which they come in contact.

The calcareous, or ſolar phoſphori, and the pyrophori, have two ſtriking circumſtances in common, which are, that they are both prepared by the application of heat, and both loſe their properties by expoſure to air; that their properties, therefore, proceed from the ſame cauſe, is extremely probable, and this cauſe may probably be the attraction of oxygen from the atmoſphere. It has been imagined, that the calcareous phoſphori loſe their property by expoſure to light; but this is a miſtake, for its properties remain uninjured by expoſure to light in cloſed veſſels.

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It must be confessed, however, that the nature both of the calcareous phosphori, and of the pyrophori, has never been fully explained. It is only necessary in this place to caution the reader against confounding them with phosphorus, the proper subject of this chapter, from which they are essentially different.

Dr. Priestley put a quantity of pyrophorus into one of the small jars used for making experiments upon air in quicksilver, then filling up the vessel with that fluid, he inverted it in a bason of the same, and threw in dephlogisticated air at different times: it always occasioned a sudden and violent accension, like the flashing of gunpowder, and the air was greatly diminished.

CHAP.

# CHAP. XXXVII.

## SULPHUR.

*General Properties of Sulphur.—Natural History of Sulphur.—Union with Earths.—With Alkalies.—Liver of Sulphur.—Artificial ſulphureous Waters.—Uſes of Sulphur.*

SULPHUR is another ſimple inflammable ſubſtance, which agrees in ſome properties with phoſphorus. Like that it melts with a gentle heat, and is capable of a gradual as well as of a rapid combuſtion, in proportion to the degree of heat applied to it.

In treating of other bodies, particularly the metallic, ſeveral have been mentioned with which ſulphur is found united in the bowels of the earth: few ſubſtances are indeed more abundant in nature than ſulphur; it alſo enters into the compoſition of animal matters, and, in a very ſmall proportion, into that of vegetables.

The ſulphur of commerce is extracted, by diſtillation, from the ſubſtance which has been ſo often mentioned under the name of pyrites, in which ſtate it is combined with iron, and is ſo hard as to ſtrike fire with ſteel. Pyrites in colour and appearance reſemble braſs; ſome pieces are cubical, but in general this mineral has no determinate form. The ſulphur obtained by the firſt diſtillation is ſeldom pure, from the ſteams of other volatile ſub-

ſtances which riſe and are condenſed with it. It is purified by being melted in a ladle, and kept in that ſtate till the impurities ſettle at the bottom. If it is an object to obtain ſulphur of the greateſt purity, this muſt be effected by ſublimation; and in this ſtate it is commonly ſold under the name of flowers of brimſtone. Even theſe, however, are ſometimes rendered impure by the ſulphur taking fire, which produces a mixture of vitriolic acid. This is effectually removed by boiling the flowers in water, which diſſolves the acid, and leaves the ſulphur in a pure and mild ſtate.

Sulphur is ſometimes found, more or leſs pure, in the neighbourhood of volcanos, in which caſe it ſeems to have been ſeparated, by ſubterraneous heat, from ſome ſubſtance with which it was previouſly combined.

The method of burning ſulphur for the preparation of the vitriolic acid has already been deſcribed when treating of that acid.

Sulphur has no action on ſiliceous earths, but very readily unites with the calcareous. It is alſo capable of combination with magneſia, ponderous earth, and volatile alkali. It unites, however, with much more violence with the fixed alkalies. All theſe combinations are of a liver colour, and are therefore called livers of ſulphur. By M. Lavoiſier they are much more properly denominated ſulphurets of theſe ſeveral ſubſtances, as ſulphuret of lime, ſulphuret of magneſia, &c. Theſe ſubſtances are ſoluble in water, and have conſiderable action on a variety of other bodies. The combinations

nations of sulphur with earths and alkalies may be all decomposed by means of acids, and the earthy sulphurets by means of the fixed alkalies. These substances, when dissolved in water, disengage a peculiar gas called hepatic gas. This gas is precisely the same, from whatever kind of sulphuret it proceeds; but none of them afford it unless mixed with water. This gas, therefore, proceeds from a decomposition of water, and is found to consist of sulphur dissolved in inflammable air. When this gas comes in contact with vital air it is decomposed, the vital air and hydrogen uniting to form water, while the sulphur is precipitated in small flakes. This gas is capable of solution in water, and by these means natural sulphureous waters may be imitated.

The chief uses to which sulphur is applied are, the making of gunpowder and vitriolic acid. It is also used in bleaching, and is an article of some importance in the materia medica.

## Chap. XXXVIII.

### THE CARBONACEOUS PRINCIPLE.

*Nature of the Carbonaceous Principle.—In what Substances principally found.—Charcoal.—Lamp-black.—Strong Attraction of the Carbonaceous Principle for Oxygen.—Its Use in the Reduction of Metals.—Plumbago, or Black Lead.—Its various Uses in the Arts.*

THE word carbon is adopted from the nomenclature of the French chemifts, to exprefs an inflammable matter which conftitutes the chief part of the weight of charcoal, pitcoal, &c. and which, with different proportions of hydrogen, or the bafe of inflammable gas, forms the different kinds of oil.

By the combuftion of carbon a peculiar acid is formed, which is foluble in water, unites with alkaline bafes, and poffeffes all the properties of acids in general, though in a weak degree. This acid has already been treated of under the name of carbonic acid gas, or fixed air.

Carbon exifts in great quantities in foffils, as the greater number of calcareous ftones and earths are found united with it; it is alfo one of the conftituent parts of the atmofphere, in both which ftates it is combined with oxygen. It is found united with earthy matter and oil in the extenfive ftrata of pit-coal, and with iron in the matter which is called plumbago, or black lead. Carbon alfo exifts in

in all vegetable and animal ſubſtances, and conſtitutes a conſiderable part of their weight, particularly of thoſe vegetable matters which are the moſt firm. The ſtate of greateſt purity to which carbon can be reduced is, by burning wood in ſuch a manner as to reduce it to charcoal, which, when well made, contains carbon united with only a very ſmall proportion of ſuch matter contained in vegetable ſubſtances as cannot be driven off with heat, ſuch as earthy and ſaline matter, with a very minute portion of iron. In order to convert wood into charcoal, the only circumſtances neceſſary are the application of heat while the air is excluded. The only elementary ſubſtances which ſeem to be univerſal in the vegetable kingdom are, carbon, hydrogen, and oxygen. The former of theſe ſubſtances has very little attraction for caloric, or the matter of heat, and therefore cannot be driven off in vapour, at leaſt by the heat of ordinary fires; the two latter, however, have a ſtrong attraction for that principle, and therefore eaſily aſſume a gaſſeous ſtate. In the ordinary temperature of the atmoſphere the carbon, hydrogen, and oxygen, which conſtitute the woody fibre, ſeem to exiſt in a ſtate of triple combination; but this is not the caſe when the temperature is altered. According to M. Lavoiſier, if a heat, not exceeding that of boiling water, is applied, one part of the hydrogen combines with oxygen, and forms water, the reſt of the hydrogen combines with a part of the carbon, and forms volatile oil, while the remainder of the carbon remains fixed at the bottom of the veſſel. If a red heat, however, is applied, no

water comes over, carbon having a ſtronger attraction at that temperature for oxygen than hydrogen has, and therefore carbonic acid is produced; and the hydrogen being left free from other combinations, unites with caloric, and comes over in the form of hydrogen gas. In this high temperature no oil is produced.

The ſolidity of charcoal depends on that of the wood from which it is procured, and the care, with which the proceſs is conducted. In general it preſerves the form of the vegetable, unleſs that was very ſucculent. Pure oils, from decompoſition by heat, afford a coal in very fine particles, called lamp-black.

In whatever manner the volatile matters can be diſpelled from vegetable or animal ſubſtances without the admiſſion of vital air, which would conſume the carbon, charcoal is produced, which contains no ingredient capable of inflammation except carbon, and therefore, with reſpect to that proceſs, may be conſidered as carbon itſelf.

" Charcoal, expoſed to the greateſt heat without the preſence of vital air, remains unconſumed and unchanged. This fact has been denied by the advocates for the phlogiſtic hypotheſis, who maintain that the pureſt charcoal, treated in this way, affords a quantity of inflammable gas. It is now, however, I believe, commonly admitted, that if the charcoal is firſt accurately dried, no inflammable gas is produced, and therefore that which has been obſerved by other chemiſts is to be attributed to the preſence of a ſmall quantity of water, which, in a high temperature, is decompoſed

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by charcoal. Dr. Prieſtley has obſerved, that charcoal has a ſtrong diſpoſition to attract humidity from the atmoſphere. He found that charcoal prepared in the evening, and kept till the morning, became ſenſibly moiſt, and unfit for nice experiments. This remarkable attraction for water is, perhaps, to be attributed to the alkaline ſalts uſually contained in charcoal.

From the very ſtrong attraction which the carbonaceous principle has for oxygen, there is no ſubſtance that can be applied to ſeparate it from that matter. Carbon, on the contrary, is capable of decompoſing all the acids except the boracic, the fluoric, and the muriatic, the unknown baſes of which have a ſtronger attraction for oxygen than itſelf.

Charcoal readily decompoſes the phoſphoric and ſulphuric acids, the baſes of which burn at a lower temperature; and this fact evinces, that the degree of heat at which the combuſtion of a body begins does not accurately mark its degree of attraction for oxygen.

From the ſtrong affinity of the carbonaceous principle for oxygen, charcoal is the moſt powerful ſubſtance which can be uſed in the reduction of metals. Charcoal has alſo another advantage over other inflammable ſubſtances in theſe operations, which is, that it bears a great degree of heat without volatilization.

According to the experiments of Lavoiſier, in the combuſtion of one pound of charcoal, two pounds, nine ounces, one drachm, ten grains of oxygen gas are abſorbed, and three pounds nine ounces one

drachm ten grains of carbonic acid gas are formed.

The carbonaceous principle, or carbon, is one of the most important substances in nature. It is one of the necessary constituent parts of animal substances, and enters into the composition of all alimentary matters, flour, sugar, mucilage, oil, &c. It is also the chief ingredient in all kinds of fuel.

Plumbago, or black lead, is found to consist of carbon combined with about one-tenth of its weight of iron. It appears to be scarcely inflammable, but may, however, be almost entirely consumed with the production of carbonic acid gas, by keeping it heated to a great degree, and agitated so as to expose it thoroughly to the air. It may be also deflagrated with a large proportion of nitre in a red heat. It is found in a separate state in a variety of places; but the species best adapted for making pencils comes chiefly from Burrowdale, in Cumberland. For this purpose it is cut into thin plates, the edge of which, being fitted into a groove in a semi-cylinder of wood, is then sawed off, so as to leave the cavity entirely filled. The black lead is retained in its place by the other half of the cylinder, which is glued on. The makers of small shot polish and blacken its surface by agitating or rolling it in a cask with powder of plumbago. This mineral is likewise used in the manufacture of razor-straps.

# CHAP. XXXIX.

## PITCOAL.

*Different Species of Coal.—Newcastle Coal.—Culm.—Slate Coal.—Cannel Coal.—Kilkenny Coal.—Bovey Coal.—Peat.—Coke.—Coal Tar.—Natural History of Coal.—Observations relative to the Deluge.*

PIT COAL is a substance of which there are many varieties, the causes of which have not been ascertained, as all the kinds afford very nearly the same results by chemical analysis. The most remarkable varieties are,

1. NEWCASTLE coal is of a black colour and shining appearance, where it has been lately broken. This substance undergoes an imperfect fusion when heated, so as to cohere or cake. It burns with a lively flame, and is nearly consumed in the fire. It does not break equally in all directions, and is composed of laminæ.

2. CULM coal. This contains a large proportion of argillaceous earth, so that after being burned its bulk is scarcely diminished. It burns with a lively flame, but its appearance is more dull and earthy than that of the former. This kind of coal is found in Sweden, and in some parts of England.

3. SLATE COAL. This has very much the appearance of some of the common kinds of slate, but it burns very easily, with a copious and bright flame. It consists chiefly of argillaceous earth, and seems to have

have only been penetrated with bituminous or coaly matter.

4. Cannel coal is of a dull black colour, breaks eaſily in any direction, and in its fracture preſents a ſmooth conchoidal ſurface, if broken tranſverſely. It is nearly conſumed in the fire, burns with a lively flame, but if ſuddenly heated flies in pieces with conſiderable violence. This inconvenience is ſaid to be removed by previouſly immerſing it in water for ſome hours*. Cannel coal does not ſoil the fingers, and admits of being turned into ſnuff boxes, inkſtands, trinkets, &c.

The word lithonthrax, uſed by ſome mineralogiſts, properly denotes ſtone coal, and ſeems moſt applicable to cannel coal, as this, from its dull and uniform fracture, has moſt reſemblance to a ſtony ſubſtance.

5. Kilkenny coal. This is perhaps the moſt free from earthy matter of all the different ſpecies of coal; the earth contained in it not exceeding the twentieth part of its weight. This coal burns with leſs flame and ſmoke †, and more ſlowly and intenſely than the cannel coal.

* It is cuſtomary in Lancaſhire to ſprinkle ſalt upon cannel coal, to prevent its flying; but I cannot ſpeak deciſively as to its effects, having never ſeen the experiment accurately made. Poſſibly the water contained in the ſalt may have ſome influence in preventing the cracking of the coal.

† Kilkenny, the town in Ireland where this coal is produced, is pleaſantly ſituated; it is watered by a clear and beautiful river, and produces alſo a black marble variegated with white ſpots. The place has therefore been proverbially characterized—“ Fire without ſmoke, air without fog, water without mud, and the ſtreets paved with marble.”

6. Sul-

6. Sulphureous coal. All those kinds of coal are called by this name, which are mixed with particles of a yellow and metallic appearance, and which are in fact a species of pyrites. In consequence of this admixture they emit, when burned, a sulphureous smell, and fall to pieces when exposed to the action of air and moisture.

7. Bovey coal, xylanthrax, is of a brown or brownish black colour, and of a yellow laminar texture. The laminæ are frequently flexible when fresh dug, though they generally harden on exposure to air. It seems to consist of wood penetrated by petrol or bitumen, and frequently contains pyrites, alum, and vitriol.

8. Peat or turf, geanthrax. It may admit of doubt how far it is proper to consider peat among the species of coal; but as some philosophers of great authority have attributed every kind of coal to a vegetable origin, and as some kinds are decisively so, the reason of this arrangement will be obvious. What is properly called peat is formed by the growth of a particular vegetable matter, peat moss, which increases to such a degree in moorish grounds as to form strata of many feet in thickness. When peat is fresh dug from below the surface, it is of a viscid consistence, but hardens by exposure to the air. It is often mixed with pyrites and stony matters, which are separated from it while soft, in which state it is formed into oblong masses for fuel. When distilled, it affords water, oil, and volatile alkali, which are precisely the products afforded by the distillation of pit-

coal. A kind of peat is found near Newbury, in Berkſhire, which contains but little earth, and conſiſts of wood, branches, twigs, roots, with leaves, graſs, ſtraw, and weeds. What is dug on moors, under the name of turf, frequently contains a mixture of peat.

Coal, when heated and inflamed to ſuch a degree as to expel the more volatile parts, forms a kind of mineral charcoal, called COKE, which is highly uſeful in the property of affording a ſtrong, clear, and laſting fire, without forming a coheſive maſs, which would prove very prejudicial in the ſmelting of metals. It is alſo uſed in drying thoſe ſubſtances which would be injured by the thick ſmoke of common coal.

Lord Dundonald was the firſt perſon who improved this proceſs, by collecting the tar and volatile alkali, which are driven off from the coal, while it is converted into coke. His method has been adopted with much advantage in ſeveral parts of Britain. The coal is put into ovens, which are heated by fires lighted beneath, and the liquid matter is forced through an iron pipe inſerted into the top of the oven, and which communicates with proper condenſing veſſels. By this proceſs a corroſive watery liquor and two ſorts of oil are obtained. Six barrels of the mixed oily matter produce about five barrels of oil of a thicker conſiſtence; of the oil thus thickened, one part is lighter than the other, which is drawn off, and is not at preſent

present applied to any use*. The thicker part is used as an inferior kind of tar.

Coal, like most other considerable masses of matter found near the surface of the earth, is disposed in beds or strata, which are sometimes parallel with the horizon, but generally form different angles with respect to it; the same stratum uniformly preserves the same direction. The strata of coal are disposed between strata of other matters. The following strata are usually found in those districts of country, both in England and Scotland, where coal abounds: whinstone, freestone, sandstone or freestone of a coarser texture, metalstone, which is a hard argillaceous substance, containing balls of iron ore and shiver, which is the most common of them all, and is an indurated bole, usually of a blackish colour.

These strata do not bear on each other in the same order in different collieries, nor are they of any uniform thickness. The strata of coal themselves are divided by other partings, called *backs* and *cutters*, into innumerable cubic, prismatic, and rhomboidal figures.

In all places where the strata lie regularly, they are divided and subdivided in the manner above mentioned, and sometimes extend uninterruptedly through a considerable district. This regularity, however, is frequently broken by gaps filled by other matter, which has evidently fallen in, in consequence of the strata having been separated

* See Bishop Watson's Essays.

from

from each other by some violent convulsion. The largest gaps are called dykes, and descend from the surface of the earth, sometimes perpendicularly, sometimes obliquely, to the greatest depths ever tried. On each side of these gaps the strata correspond, but they are often sunk several feet or fathoms lower on one side than the other, and this is called a dip.

With respect to the origin of pitcoal, it is the opinion of Dr. Black, Bishop Watson, and other philosophers of high reputation, that the strata of coal were formerly large collections of vegetable matter at the surface of the earth. In distant ages, Britain was probably almost entirely covered with immense forests and collections of peat moss, which (according to the opinion of these naturalists) being covered with quantities of sand or earth brought by floods, or by more gradual causes, as the falling of the substance of the neighbouring hills, has been pressed and consolidated, in course of time, into the substance called pit coal. The surface of the earth has also been probably rendered unequal in a variety of places by the action of earthquakes; this would give rise to the formation of lakes in those places which were depressed. In this manner, a quantity of vegetable matter would become covered by deposition from water. Volcanic eruptions must often also have overwhelmed large collections of vegetable matters. We even find vegetable matter in an intermediate state between organized vegetable substances and coal; for peat has still some small remains of organic texture, but seems chiefly

chiefly to confist of oily and inflammable matter, which only requires time and the preffure of fupe-incumbent ftrata to convert it into the firm and compact texture of coal. In fome places, the remains of forefts have been obferved converted into an imperfect pit coal, in which the trunks, branches, bark, and roots of trees, are difcernible. In the neighbourhood of coal pits, impreffions of vegetable matters, and particularly of fern, are ufually obfervable. Now it is remarkable, that both peat mofs and fern are produced on wild and uncultivated lands, and this renders it ftill more probable, that coal in general owes its origin to peat mofs. Coal is found in thin and broad ftrata, fuch as might be expected on the fuppofition of its being derived from the decay of peat mofs, or collections of other vegetables on the furface of the earth. Coal is often covered with matter which cannot be fuppofed to have been created in its prefent ftate, as fandftone, the particles of which are evidently owing to the motion and friction occafioned by water. It has been already mentioned, that the products afforded by the diftillation of peat mofs and pit coal are precifely the fame. We know of no fubftance purely and unqueftionably mineral, which affords products at all fimilar, and it therefore on the whole feems probable, that the ftrata of coal found in different countries, however extenfive, owe their origin to vegetable matter. The bituminous matters feem alfo to be exudations from vegetable matters buried in the earth.

In

In confirmation of the ſame opinion, I add the following extract from the late ingenious Mr. Whitehurſt's Inquiry into the original State of the Earth. 'All the ſtrata incumbent on coal, whether argillaceous ſtone or clay, contain figured ſtones, repreſenting a vaſt variety of vegetables, or the impreſſions of them, as reeds of various kinds, ſtriated and jointed at different diſtances, the euphorbia of the Eaſt Indies, the American ferns, corn, graſs, and many other ſpecies of the vegetable kingdom. They are incloſed in the ſolid ſubſtance of the ſtone, &c. Theſe vegetable forms, and the ſtrata containing them, are the certain indication of coal, not only in Derbyſhire, but in every part of the kingdom which I have viſited; and I am informed, that the ſame phenomenon holds equally true in every other part of the world yet explored.' In general, the ſtone which holds foſſil plants is either very hard and cloſe, or bituminous, ſo as to afford no acceſs to water.

The great difficulty in this hypotheſis reſults from the immenſe quantities of theſe matters which are found in the earth, and this difficulty can only be removed by referring to a fact, which is ſupported by the traditions of every nation upon earth, the univerſal deluge.

Among many other curious obſervations, relating to the deluge and its remains, made by Dr. Scheuchzer and his brother, the Doctor informs us of the trunk of a tree, nine Paris feet in length, with ſome part of its branches ſtill left upon it, which is lodged upon the ſummit of mount Stella, the chief

5 of

of all the Alps of Switzerland, which, according to the barometer, is more than two English ſtatute miles perpendicular in height, and four thouſand feet higher than any trees or vegetables are obſerved to grow; he concludes, therefore, that it was left there by the ſubſidence of the waters of the deluge. Another modern writer alſo very properly remarks, 'When we find on any ſtones an exact reſemblance of a plant, a leaf, or ſome fruit, that we are acquainted with, if theſe leaves are bent or folded, if they croſs each other, or lie one upon another, they are certain indications that the plant or fruit ſo repreſented is an impreſſion made by a natural body*.' Specimens of this deſcription are frequently found.

Not only vegetables, however, but parts of animals alſo, are met with, deeply plunged in the ſtrata of the earth, for the preſence of which, in ſuch ſituations, we cannot account, except by ſuppoſing, that they were depoſited during the deluge, when not only the windows of heaven were opened, but the fountains of the great deep were broken up; expreſſions which denote, in the ſtrong ſtyle of oriental imagery, the extenſiveneſs of that vaſt diſturbance or convulſion which happened to this globe. A foſſil ſkeleton of an alligator, twelve or fourteen feet in length, was diſcovered in the cliff of an alum rock, near Whitby, in Yorkſhire. In a gravel pit of Suffolk, abounding with foſſil ſhells, the entire ſkeleton of a whale was diſcovered,

* Le Pluche Spect. de la Nature, Dial. 25.

 the

the bones of which, when they became friable by exposure to the air, were employed by a farmer for the manuring of his land. Fragments of an elephant's tooth were dug from a gravel pit at the end of Gray's Inn Lane, at the depth of twelve feet. From these and other facts it seems probable at least, that this part of the world, before the flood, contained animals which now are very rarely found, or are totally incapable of existing in such a climate. This consideration will lead us to conclude, that the deluge not only destroyed the greater part of the animals then existing, but produced a considerable alteration in the constitution of the globe, and a permanent revolution in some of the laws of nature, of which the change that took place in the length of human life is one striking instance. The earth, and almost every part of it, is stored with the remains of trees, plants, and fruits; of fish, testaceous, crustaceous, and squamous, and of other occasional inhabitants of the waters. The spoils of land animals are also met with, but in much smaller quantities, which it is not difficult to account for, when we consider, that the waters of the sea occupy more than twice as much of the globe as the land, and that the waters are much more copiously supplied with animals of considerable magnitude, than the land. Add to this, that the classes of corallines, lithophuta, and many of the testaceous kinds, are of a substance as hard as stone, and of a much more durable texture; whence it is not to be accounted a matter of surprize that they abound so much in the earth in the form of petrifactions. We are to recollect also, that the catas-

trophe of a deluge would ſoon corrupt, deſtroy, and diſperſe the parts of ſuch living creatures as die in the waters; while the natives of the ſea would ſtruggle with the difficulties of an inundation, and be at laſt depoſited, perhaps alive, in the earth, when the ſettlement of the ſtrata took place, and the waters retreated, as it is evident that many of them actually were, from the poſtures and circumſtances in which they have been diſcovered*.

* See Jones's Phyſiological Diſquiſitions.

## Chap. XL.

### NAPHTA, PETROLEUM, BARBADOES TAR, &c.

*Nature and Properties of Naphta.—Burning Fountains.—Petroleum.—Mineral Pitch, or Barbadoes Tar.—Lake Asphaltes.—Asphaltum; how collected.—Elastic Bitumen.—Component Principles of these Substances.*

ALL these substances are of the bituminous kind, and are, indeed, all of the same nature, but differ in consistence. Naphta is an oily fluid, which, in its greatest degree of purity, is nearly colourless, is extremely volatile and subtile, and so light as to float even on spirits of wine. It has a strong oppressive smell, and evaporates spontaneously. Like other oils, it burns with smoke. It is said to be gathered at the surface of certain wells in Persia, and is rarely found in Europe.

The vapour of naphta, which issues through the crevices of the earth, is generally supposed to be the cause of the flame which is sometimes observed on waters, fountains, &c. At Chittagón, in the East Indies, there is a fountain which bursts into flame of its own accord, whenever it has been extinguished by accident; this fountain has its deity and its priests; and some Europeans, suspecting the whole to be a pious fraud, pulled down the wall, &c. but found that the vapour actually kindled spontaneously when put out. It is possible, however,

ever, that this flame may be fed by inflammable air instead of naphta.

Petroleum, which is of a thicker consistence, and more weighty than naphta, is much more common. It is of a yellow or brown colour, and is found in Switzerland, Sicily, Italy, and France. It issues from the crevices of rocks, or is found floating on the surface of springs. The different kinds of petrolea, on distillation, yield naphta, while a coaly residuum remains in the retort.

Barbadoes tar is of a thicker consistence than petroleum, and is also called mineral pitch; it was formerly found near Babylon, and constituted, according to Vitruvius, when mixed with lime, the cement which was used in building the walls of that city. It is at present found in several parts of Europe and in America, where it drops, or distils, gradually from rocks.

Asphaltum is a substance much resembling Barbadoes tar; it is also called Jews pitch, and is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah anciently stood. From the production of this substance this was called the Lake Asphaltes, from a Greek word denoting bitumen. The bitumen floating on the surface of the water is hardened by the heat of the sun, and is in that state collected by the Arabs on the shore, where it is thrown. The eastern asphaltum is seldom brought to Europe, but is used by the inhabitants as pitch.

All these thicker bitumens may be rendered thinner by distillation, and may be converted into

an oily fluid, the tenuity of which is increased by the repetition of the process; at every distillation a quantity of charcoal, earthy matter, and carbonic acid gas, being separated from them.

In *Observations sur la Physique*, for January, 1788, vol. xxxii. M. de la Metherie makes mention of a mineral elastic bitumen analogous to the caoutchouc, or elastic gum, and which is found in Derbyshire.

The production of all these bitumens is attributed to the action of subterraneous fire on strata of pitcoal, by which the oily parts are separated and sublimed in the same manner as by artificial heat.

Bishop Watson mentions a curious experiment, which illustrates the relation of these four bitumens to each other. The most transparent oil of turpentine, resembling naphta, may be changed into an oil resembling petroleum, by mixing it with a small portion of vitriolic acid; with a larger proportion of the acid the mixture becomes black and tenacious like Barbadoes tar, and the proportions of the ingredients may be so adjusted, that the mixture will even acquire a solid consistence like asphaltum.

CHAP.

# CHAP. XLI.

## JET, AMBER, AMBERGRIS, AND MINERAL TALLOW.

*General Properties of Jet.—Its Nature and Origin.—Amber.—Acid of Amber.—Natural Hiſtory of Amber.—Different Opinions of its Origin.—Ambergris.—Its Natural Hiſtory.—Mineral Tallow.*

JET is a very compact bitumen, harder than aſphaltum, always black, and ſuſceptible of a good poliſh. It is ſo light as to ſwim on water, becomes electrical when rubbed, and is called black amber. When burned it emits a bituminous ſmell. Jet ſeems nearly allied to coal, and particularly to that ſpecies which is called cannel coal; it is diſtinguiſhed chiefly by its ſtructure, being compoſed of fibres parallel to each other like thoſe of wood. It ſeems in fact to be wood, which has been long buried in the earth, and penetrated by mineral ſteam, ſo as to aſſume the appearance and ſolidity of coal.

Amber is the ſubſtance known to the ancients under the name of electrum and ſuccinum. In this ſubſtance the property, which certain bodies have, of attracting light ſubſtances, when rubbed, was firſt obſerved, and was therefore called electricity. The moſt valuable amber is perfectly tranſparent, of a pale yellow, and is much more eſteemed when it happens to contain any extraneous ſubſtance, ſuch as leaves, inſects, &c. When broken it preſents a

polished surface at the place of the fracture. Amber does not readily dissolve in any fluid we are yet acquainted with. Spirit of wine has some small effect upon it, and from this combination a tincture is produced, but the quantity it dissolves is very small. When applied to the flame of a candle it readily takes fire, and burns with a bright white flame and thick smoke, and leaves a considerable quantity of charcoal. Amber exposed to heat, without the action of flame, softens and swells very considerably. Distilled in a retort by a heat gradually raised, it affords a watery fluid of a red colour, manifestly acid; this acid spirit retains the strong smell of amber; an acid volatile salt afterwards passes over, which crystallizes in small white or yellowish needles in the neck of the retort. This salt is succeeded by a white and light oil much resembling naphta; by continuance of the process, and in proportion as the heat is increased, the oily matter which comes over is coloured and more viscid, like petroleum. What remains at the bottom of the retort is a black mass resembling asphaltum. It appears, therefore, from distillation, that the analogy of amber with the other bitumens is very strong.

A gentle heat is sufficient to raise the concrete volatile salt of amber, and care must be taken to regulate it so as not to force up the oil, when it is required to have the salt in a separate state. This saline matter was for some time supposed to be an alkaline salt, but has been since found to be an acid of peculiar

properties,

properties, and capable of combination with alkalies, earths, and metallic calces.

Amber is usually dug out of the earth, and abounds particularly in the Prussian dominions. Wood is usually found near it, and it is therefore believed to be of vegetable origin. Its analysis seems to shew, that it consists of an oil rendered concrete by combination with an acid. The most transparent specimens are usually found on the sea-shore, particularly on the shores of the Baltic, in Ducal Prussia. Amber is not always of a yellow colour; it is sometimes brown, sometimes quite opake, and sometimes black. Some have supposed that it is entirely of mineral origin, but this is disproved by its distillation, and by the foreign bodies which are frequently contained in it, and which seem to demonstrate that it was once in a fluid state.

Hoffman and Newman say, that it is found upon the sea-shore, or upon the surface of waters, particularly after great storms, when it is collected by means of nets; but that the greater part of it is dug out of pits. The first stratum is sand, then clay, then a layer of branches and trunks of trees, then a considerable quantity of pyrites, whence vitriol is prepared; and lastly, a bed of sand, through which the amber is dispersed in small pieces, or collected together in heaps. This account greatly favours the idea of the vegetable origin of amber; but Wallerius asserts, that the black and dark coloured amber is often found in the bowels of cetaceous fishes. M. Girtanner has a peculiar opinion on this subject; he thinks that amber is a vegetable

oil

oil rendered concrete by the acid of ants; it is that kind of ants called formica rufa by Linnæus, which prepares it, according to this author. These insects dwell in old forests of fir trees, where the fossil amber is found, which, when first dug, is ductile like wax, and becomes hard on exposure to air. No insect is so commonly found in amber as the ant.

Ambergris is of much the same nature as amber, but differs from it by its particular consistence, which nearly approaches to that of bees wax. Its structure is sometimes like bees wax, but sometimes it is granulated, and appears opake, or of a dark grey. Experiments prove that it resembles amber in its nature. When analyzed it is found to consist of phlegm, a volatile acid partly fluid, oil, and a little coaly matter. It dissolves more readily in spirit of wine than amber.

It is most common in the Indian seas, on the eastern coast of Africa, Madagascar, &c. and is found either floating on the sea, or cast on the sea-shore. In this substance animal and vegetable remains are sometimes found, as for instance, parts of birds, &c.

The origin of this substance is probably the same with that of amber. According to M. Aublet (in his *Histoire de la Guiane*) it is nothing more than the juice of a tree inspissated by evaporation; and if this is true, it is a substance which belongs properly to the vegetable kingdom. The tree which is said to produce it grows in Guiana, and is called *cuma*, but has not been examined by other botanists. When a branch is broken by high winds, a large quantity

quantity of the juice exudes; and if it chances to have time to dry, various masses (some of which have been so large as to weigh one thousand two hundred pounds and more) are carried into the rivers by heavy rains, and through them into the sea; afterwards they are either thrown on the shore or eaten by some fish, chiefly the spermaceti whale, known by the name of *physiter-macrocephalus* among ichthyologists. This kind of whale is extremely voracious of this gum-resin, and swallows such large quantities when it meets with it, that it generally becomes sick, so that those employed in the fishery of these whales always expect to find some amber mixed with the excrements and remains of other food in the bowels of those whales which are lean. Various authors, among whom is Father Santes, in his *Ethiopia Orientalis*, who travelled to various places on the African coast, and Bomare, say, that some species of birds are also fond of eating this substance, as well as whales and other fishes. This accounts very well for the claws, beaks, bones, and feathers of birds, parts of vegetables, shells, and bones of fish, and particularly for the beaks of the cuttle-fish, *sepia octopedia*, which are sometimes found in the mass of this substance. M. Aublet brought specimens of this gum-resin, which he collected on the spot, from the cuma tree at Guiana. It is of a whitish brown colour, with a shade of yellow, and melts and burns like wax on the fire. M. Rouelle examined very carefully this substance, brought over by M. Aublet, and found that it produced exactly the same results as good amber. These

These obſervations ſeem to place it beyond a doubt, that both amber and ambergris are vegetable products, and that thoſe who, from having found theſe ſubſtances in the inteſtines of whales, concluded that it was a fæcal matter of thoſe animals, were miſtaken.

Mineral tallow is a very peculiar ſubſtance. It was found on the coaſts of Finland, in the year 1736. Its ſpecific gravity is 0.770, whereas that of tallow is 0.969. It burns with a blue flame and a ſmell of greaſe, leaving a black viſcid matter, which is more difficultly conſumed. It is found in ſome rocky parts of Perſia, but ſeems mixed with petroleum. Dr. Herman, of Straſburgh, mentions a ſpring, in the neighbourhood of that city, which contains a ſubſtance of that nature diffuſed through it, which ſeparates on ebullition, and may then be collected. The origin of this ſubſtance is unknown.

CHAP.

# Chap. XLII.

## OF THE DIAMOND, CONSIDERED AS AN INFLAMMABLE SUBSTANCE.

*Experiments proving the inflammable Nature of the Diamond.—Experiments of M. Cadet.—Of D'Arcet.—Vital Air necessary to the Combustion of the Diamond.—Experiments of Lavoisier.—Further Experiments.—Conclusion from the whole.*

THE external appearance of this peculiar and beautiful ſubſtance has been already deſcribed, but it is proper alſo to conſider it in another point of view, as from ſome extraordinary experiments many naturaliſts are diſpoſed to include it in the claſs of inflammables.

It has long been underſtood that diamonds, expoſed to a high degree of heat, entirely diſappear at the inſtant that an appearance of combuſtion is obſerved. M. Cadet expoſed diamonds in covered and luted * crucibles to the violent heat of a forge during two hours, by which the diamonds only loſt one ſixteenth part of their weight: he is of opinion, that the conſumption of diamonds in open veſſels is not a true volatilization, but merely an exfoliation occaſioned by the expanſion of the air contained between the laminæ of the diamond,

* Luting is a kind of earthy cement uſed by chemiſts, and formed in different ways.

by which it is broken into portions ſo minute as to eſcape obſervation. M. D'Arcet oppoſes to the above explanation, the eſcape of the ſubſtance of the diamonds through the moſt ſolid porcelain crucibles, and the luminous appearance noticed by Macquer, and which was afterwards obſerved by M. Roux to be an actual flame. It has, indeed, even been found, that diamonds incloſed in a ball of porcelain earth, and expoſed to heat, have been totally conſumed; the ſpace which the diamond occupied was found empty; no traces of it could be diſcovered, and yet the ball of porcelain, which was hardened by the heat, was apparently entire. This experiment, according to Fourcroy, has been frequently repeated with the ſame extraordinary reſult. It is found, however, that if the diamond is embedded in charcoal, and carefully incloſed in ſeveral crucibles placed within each other, and the whole covered with cement, it does not diſappear from expoſure to a very violent heat; it is only rendered black at its ſurface, and when this cruſt is taken off, it appears in its original ſplendor. It is therefore concluded, that perfect excluſion from vital air is ſufficient to prevent the conſumption of the diamond, as well as of all other inflammable ſubſtances; and it is therefore neceſſary to ſuppoſe, that the porcelain earth, in which other diamonds were incloſed, ſuffered ſome ſmall ſeparation from expoſure to heat, which, though ſo minute as to eſcape obſervation after the ball was cold, were yet ſufficient to admit the air. This opinion has been fully confirmed by ſome experiments of M. Lavoi-

ſier,

ſier, who found, that diamonds are only conſumed in proportion to the quantity of vital air to which they are expoſed. He alſo found, that the combuſtion of the diamond was attended with the formation of carbonic acid gas. This diſcovery may probably throw as much light on the nature of the diamond, as his other diſcoveries have diffuſed through almoſt the whole extent of natural ſcience. Some curious experiments on the diamond are alſo detailed in the Annales de Chimie for November 1791. A piece of iron wire was faſtened to the diamond intended to be burned, the iron was heated red hot, and in that ſtate plunged into a jar of vital air; the iron rook fire, and communicated the inflammation to the diamond, which burned in a moſt vivid manner, and with uncommon brightneſs. The Brazil diamonds, however, it is neceſſary to remark, could not be made to burn in this way. On the whole, there can be no doubt that the diamond is truly an inflammable ſubſtance; but a repetition of theſe expenſive experiments is neceſſary, in order accurately to aſcertain its nature, and to reconcile ſome differences in the reſults of ſuch experiments as have been already made.

CHAP.

# Chap. XLIII.

## THE STRUCTURE OF THE EARTH.

*The Curiosity of Man on this Topic limited by the Weakness of his Powers.—The Body of the Earth disposed in Strata.—Declivities of Mountains—Disposition and Order of the Strata.—Caldy Island.—Where Metals are usually found.—Probable State of the Earth at its Creation.—Laws by which Alterations would be produced.—Fossil Shells, &c. accounted for.—Formation of Islands, &c.—Other Irregularities of the Earth's Surface explained.*

AFTER the preceding survey of the natural contents of this globe of earth, and of their component principles, the next object of attention is the earth itself, and the general arrangement of those substances of which it is composed. These are neither disposed in a regular series, according to their specific gravities, nor yet thrown together in total disorder, as if by accident or chance. Human industry has hitherto been able to penetrate but a very little way into the bowels of the earth, and we can but know little of its interior parts. The depth of the earth, from the surface to the center, is more than four thousand miles, and yet the deepest mine in Europe, that at Cotteberg, in Hungary, is not more than one thousand yards deep; "the greatest depth, therefore," says an excellent writer, "to which avarice has ever yet penetrated, may be compared to the puncture made in the body of an elephant by the proboscis of a gnat."

From

From what has been discovered, however, of those parts which lie most contiguous to our observation, naturalists have compared the structure of the earth to the leaves of a book, or the coats of an onion. Except, indeed, in some of those immense mountains, which have existed from the creation, or at least from the deluge, where the matter, from whatever cause, is more homogeneous, the earth is found to consist of various strata, or layers, which differ according to the circumstances of climate and situation. The surface, in general, evidently consists of a confused mixture of decayed animal and vegetable substances and earths rudely united together; but when we have penetrated below the surface, we find the materials of the globe arranged in a more regular manner. Sometimes, indeed, we find heaps of stone, which do not consist of layers, but are confused masses of unequal thickness, and are called rocks. The strata are, in general, extended through a whole country, and, perhaps, with some interruptions and varieties, through the globe itself. These extensive bodies are found most regular when the country is flat, being, in that case, nearly parallel to the horizon, though frequently dipping downwards in a certain angle; in many places the beds have a wave, as where the country consists of gently waving hills and vales; here too they generally dip. In travelling a mile we, perhaps, pass through ground composed mostly of sand, in another mile we find it, perhaps, composed of clay; and this is occasioned by the edges of the different strata lying with an obliquity to the horizon. By

the ſame kind of projection mountains, or ridges of mountains, are produced, which, in general, have what is called a back and a face, the former ſmoother and the latter more rugged. We generally find too, on one ſide of a mountain, a more gradual aſcent than on the other, which is occaſioned by the ſtrata, which have riſen above the general level of the country being abruptly broken off. Mountains are in general more abrupt towards the weſt, and have a more gentle declivity towards the eaſt; hence the weſtern coaſt of countries is almoſt always ſteeper than the eaſtern. The back of a mountain ſhews the obliquity with which the ſtrata ſink into the ground; the abrupt edge of the ſtrata becomes more ſloping, as time, producing a gradual decay, draws the rubbiſh from above. Where the face of a country is ſo irregular, its appearance depends on the different hardneſs or ſoftneſs of the ſtrata. The abrupt rocks, which we obſerve in many parts, ſeem to have been compoſed of an adventitious mixture of different ſtrata, which have reſiſted the injuries of time with unequal force.

Between the ſtrata, layers of different clays are interpoſed, which are called by the miners way-boards; they are ſeldom more than four or five, and in ſome inſtances not more than one foot thick; they ſerve to mark and diſtinguiſh the different ſtrata, for in fact the ſtrata are themſelves compoſed of different laminæ *.

* Whitehurſt, Chap. XVI.

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Every part of a ſtratum may be conſidered as equally thick when covered with an incumbent bed; but when expoſed to the action of the air, and other external agents, a great part of it, whether grit, lime-ſtone, or toad-ſtone, is decompoſed and converted into earth or mould. Immediately under the ſoil the fragments of ſtone are ſmall, and gradually increaſe to the depth of fifteen or twenty feet, where it commonly appears ſolid, and fit for the maſon. Strata are uſually interrupted by clefts or fiſſures at different diſtances, which ſeem to have been the effects of violence. In theſe fiſſures only the ores of metals are to be found.

It has been remarked, that we cannot, by digging into the earth, obtain a view of the poſition and nature of the ſtrata for more than ſome few hundreds of yards. There is, however, one curious inſtance of an iſland, near the coaſt of Pembrokeſhire, called Caldy Iſland, where the earth ſuffered the action of ſo unuſual a diſruption, that the ſtrata, of which the whole iſland is compoſed, are placed in a vertical poſition, ſo that their edges are all expoſed to view, and they may be obſerved in ſucceſſion from one end of the iſland to the other. Here then we have the ſingular opportunity of obſerving in what order they were originally placed, to the depth of two miles. At one end of the iſland they are not more than a foot thick, but increaſe, as we proceed, till they terminate in a ſtratum of red ſtone, more than a mile in thickneſs, which, with good reaſon, is ſuppoſed to have been the loweſt of them all before they were elevated and thrown upon their

edges. The thinner ſtrata, which were originally uppermoſt, have foſſil ſhells and corallines in them; but I have not heard that any thing like the traces of lava are to be found to countenance the ſuppoſition, that this ſingular accident was occaſioned by the exploſive force of a volcano.

The order of the ſtrata in Derbyſhire is as follows: 1. Millſtone-grit, a coarſe ſand-ſtone compoſed of granulated quartz and quartz pebbles. 2. Shale or ſhiver, or black laminated clay, much indurated. 3. Lime-ſtone, in various laminæ. 4. Toad-ſtone, a black porous ſubſtance, hard, reſembling ſcoriæ, and apparently a volcanic production. 5. Lime-ſtone. 6. Toad-ſtone. 7. Lime-ſtone. 8. Toad-ſtone. 9. Lime-ſtone again. Such (the toad-ſtone excepted) appears to be the general order in which the ſtrata appear through the different regions of the earth, or at leaſt wherever the lime-ſtone predominates, which is in a conſiderable proportion, though it muſt be remarked that the largeſt mountains are chiefly granite. Wherever, therefore, the firſt of theſe ſtrata appears on the ſurface, the ſecond lies certainly under it, the third under the ſecond, &c. ſtill excepting the toad-ſtone, which, being a volcanic production, may be ſuppoſed to be in ſome meaſure caſually interpoſed.

The toad-ſtone interſects all the mineral veins, and cuts off all communication between the upper and lower parts of the fiſſures, being continued horizontally in one uninterrupted maſs. Toad-ſtone is of an extremely hard and cloſe texture, ſo much ſo as even to prevent water from filtering through it, at leaſt in

any

any quantity. It is perfectly ſimilar to Iceland lava in appearance, and in being unaſſailable by acids. It has no fiſſures; and frequently fills up the fiſſures of the other ſtrata; in fine, it being not univerſal, but only an occaſional appearance, there is the utmoſt probability that it is a ſpecies of lava. It being inſerted between the other ſtrata ſeems alſo to afford a proof, that it originally flowed from a volcano, the funnel or ſhaft of which did not approach the open air, but diſcharged its fiery contents between the ſtrata in all directions. When the toadſtone is dug through, however, and the vein or fiſſure purſued, the miner is never diſappointed in meeting it again, as ſoon as he arrives at the ſtratum of lime-ſtone *.

The ſtrata of coal, argillaceous ſtones, clay, &c. are always incumbent on the ſtrata of grit, ſhale, and lime-ſtone. The former are ſeldom in ſtrata of above twenty feet thick, and generally not more than four or five; the latter are in ſtrata of from fifty to one hundred and fifty feet in thickneſs, or depth †.

All beds of gravel are ſuppoſed to have been depoſited either by rivers or by the action of the ſea, and the ſtones that compoſe them to have been rounded by attrition. It is no inconſiderable proof in favour of ſuch a conjecture, that ſea ſhells, &c. are ſo frequently found with gravel.

The argillaceous ſtrata are only productive of iron and coal. The ores of copper, lead, zinc, &c.

* Whitehurſt, Chap. XVI. † Ib.

are confined entirely to the lime-ſtone ſtrata, a few inſtances excepted, where they are found in ſhale.

The diſpoſition of the ſuperficial ſtrata, however, differs in mountainous and champaign countries. '.In a well which was dug at Amſterdam, to the depth of two hundred and thirty feet, the following ſubſtances were found in ſucceſſion *: ſeven feet of vegetable earth, nine of turf, nine of ſoft clay, eight of ſand, four of earth, ten of clay, four of earth, ten of ſand, two of clay, four of white ſand, one of ſoft earth, fourteen of ſand, eight of clay mixed with ſand, four of ſea-ſand mixed with ſhells, then an hundred and two feet of ſoft clay, and then thirty-one feet of ſand.

' In a well dug at Marly, to the depth of an hundred feet, M. Buffon gives us a ſtill more exact enumeration of its layers of earth. Thirteen feet of a reddiſh gravel, two of gravel mingled with a vitrifiable ſand, three of mud or ſlime, two of marle, four of marly ſtone, five of marle in duſt mixed with vitrifiable ſand, ſix of very fine vitrifiable ſand, three of earthy marle, three of hard marle, one of gravel, one of eglantine, a ſtone of the hardneſs and grain of marble, one of gravelly marle, one of ſtony marle, one of a coarſer kind of ſtony marle, two of a coarſer kind ſtill, one of vitrifiable ſand mixed with foſſil ſhells, two of fine gravel, three of ſtony marle, one of coarſe powdered marle, one of ſtone, calcinable like marble, three of grey ſand, two of white ſand, one of red ſand ſtreaked with white, eight of grey ſand with

* Varenius, as quoted by M. Buffon, p. 358.

ſhells,

ſhells, three of very fine ſand, three of a hard grey ſtone, four of red ſand ſtreaked with white, three of white ſand, and fifteen of reddiſh vitrifiable ſand.'

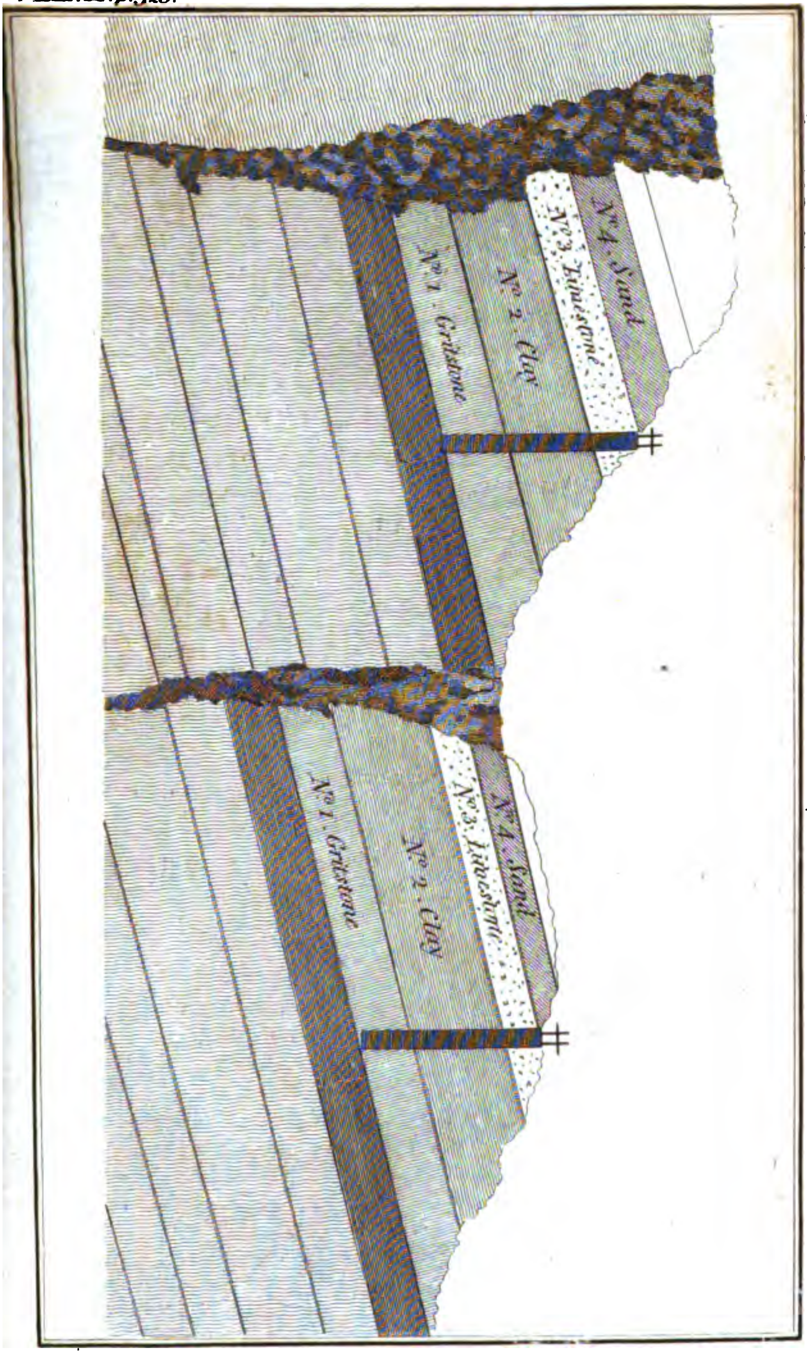
The direction too in which the ſtrata are found is alſo exceedingly different in different ſituations. 'When the continuity,' ſays Mr. Jones, 'of the ſtrata is interrupted by a fracture, the ſtrata are thrown out of that horizontal poſition which is natural to them, and make an angle with the horizon; which may be called the angle of their elevation or depreſſion; the miners call it their *dip*. In this caſe, if the ſucceſſion of ſtrata is accurately noted on one ſide of the fracture, where a vein of coal or metal is found amongſt them, it may thence be learned where the ſame vein will occur again on the other ſide of the fracture; becauſe it will be found adjacent to the ſame ſtrata as before. When the edges of the ſtrata, on each ſide a fiſſure, are thus parted and miſmatched, they are ſaid to *trap*; and the ſpace between them is filled up with rubble, or ſtones, or minerals, &c. Sometimes theſe fiſſures are the richeſt parts of the ſoil, containing ſuch matters as are not to be found elſewhere *. In fig.

* Some of the fiſſures in Cornwall are near twenty feet over, and commonly full, or near it, of metallic and mineral matter. The fiſſures at the greateſt depth are generally largeſt: as we aſcend they become gradually leſs, but more frequent and numerous: inſomuch that if the globe was divided in two, and the ſtrata viewed upon the face of the ſection, the figures would appear after the manner of a tree: at the bottom a large trunk, which higher up is divided into branches, which break into

fig. I. plate I. F. represents the fissure, by which the strata are parted, and which is filled up with extraneous rubbish, carried in after the strata were parted. The black vein of coal on the left side is found with five other strata above it; but being interrupted by the fissure F. where it *comes out to the day*, the stratum of sand, No. 4, on the right side, on account of the trapping, is found opposite to it: thence it is to be collected, that the fourth stratum below that sand will be coal; and when the angle of the *dip* is observed, it may be known where to sink a pit, and where the coal will again appear to the day; provided the figure of the surface of the ground will permit it to shew itself. When I was once at the bottom of a lead mine in Derbyshire, a miner informed me, that the veins of the metal always make a greater angle with the horizon than the sides of the mountain do, in which they are found and come out to the day; which was probably occasioned by the descent of the waters of the flood, tearing away much of the matter from the summit, and lodging it upon the sides and in the vallies beneath, after the strata had received their inclination.'

into lesser, and at the top into twigs. But the branches are not continued in a strait line: they start afresh, at some little distance on one side, as in fig. 2. that by an intervening boundary the metallic matter might be detained in its descent, and prevented from sinking away to the bottom of the earth. See Mr. Hutchinson's Observations in the year 1706, p. 316, 317.

With


N° 1. Gritstone
N° 2. Clay
N° 3. Limestone
N° 4. Sand
N° 1. Gritstone
N° 2. Clay
N° 3. Limestone
N° 4. Sand

With reſpect to the more internal parts of the earth, for the reaſons aſſigned in the beginning of this chapter, nothing can be advanced with certainty, and hypotheſes cannot be relied on.

By ſome it has been ſuppoſed, that the center of the earth conſiſts of fire. Mr. Kirwan, however, has ſatisfactorily proved, that the notion of a central fire or heat is void of foundation. Since no authentic obſervation aſſures us, that this heat increaſes in proportion as we penetrate below the ſurface of the earth; on the contrary, many experiments ſerve to evince, that it rather decreaſes (though never to leſs than thirty-ſix degrees) and that its variation at the ſame diſtance below the ſurface conſtantly bears a proportion with the variation of the ſolar heat at the ſurface.

The more general opinion is, that the ſtrata originally lay horizontally, and were formed by a depoſition from water. The arguments for this opinion are forcible. The relics of a variety of ſubſtances, which we now find only in the ſea, are found in rocks and mountains, at a very great diſtance from it. In ſtrata of lime-ſtone, every where diſtant from the ſea, we find the remains of ſhells, &c. the productions of the ocean. Other circumſtances prove, that the ſea has covered parts of the earth, which are now at a great diſtance from it, and that the various directions which the ſtrata now have were not their direction at their firſt formation. That the frame of this earth has undergone ſome violent concuſſion is evident, as was already ſtated, from the traces which ſtill remain. The ſtrata we have ſeen are often broken

in

in different directions, in general perpendicularly; ſo that the parts of the ſtrata are ſeparated from each other. The width of theſe rents is different, ſometimes a few inches, ſometimes many yards. They are very commonly filled up with ſubſtances different from the compoſition of the ſtrata. In mountains there is ſometimes obſerved the appearance of a white ſtone, which paſſes through it like a vein. This has been a rent filled up with a particular kind of ſtone. Theſe are very common in the ſtrata of coal. They are generally of conſiderable hardneſs, and in them metallic ſubſtances are uſually found. When any of theſe are not filled up with extraneous matter, the internal ſurface is ſet with very beautiful and regular cryſtals of the ſparry kind, projecting into the cavity.

Some have attributed theſe irregularities to frequent earthquakes; others have imagined that the globe, before the deluge, contained an immenſe body of water, covered over with a cruſt of earth, which at the deluge was broken through, and partly ſunk in the waters, the elevated edges forming the mountains and high lands, while the lower were overflowed by the ocean; others have ſuppoſed, that the near approach of a comet has thrown the materials of the globe into confuſion. Buffon imagines, that the ſea is continually changing its bed, and is conſtantly waſhing away the ground from one place to another*. But the arguments and obſervations

* A ſhort ſketch of the moſt remarkable theories of the earth is given by a popular writer, and it may be amuſing to

vations of Mr. Whitehurst are more deserving attention, since he is almost the only writer on

to some readers to trace these vagaries of the human imagination.

'The first who formed this amusement of earth-making into system was the celebrated Thomas Burnet, a man of polite learning and rapid imagination. His *Sacred Theory*, as he calls it, describing the changes which the earth has undergone, or shall hereafter undergo, is well known for the warmth with which it is imagined, and the weakness with which it is reasoned, for the elegance of its style, and the meanness of its philosophy. The earth, says he, before the deluge, was very differently formed from what it is at present: it was at first a fluid mass; a chaos composed of various substances, differing both in density and figure: those which were most heavy sunk to the center, and formed in the middle of our globe an hard solid body; those of a lighter nature remained next; and the waters, which were lighter still, swam upon its surface, and covered the earth on every side. The air, and all those fluids which were lighter than water, floated upon this also; and in the same manner encompassed the globe; so that between the surrounding body of waters, and the circumambient air, there was formed a coat of oil, and other unctuous substances, lighter than water. However, as the air was still extremely impure, and must have carried up with it many of those earthy particles with which it once was intimately blended, it soon began to defecate, and to depose these particles upon the oily surface already mentioned, which soon uniting, the earth and oil formed that crust, which soon became an habitable surface, giving life to vegetation, and dwelling to animals.

'This imaginary antideluvian abode was very different from what we see it at present. The earth was light and rich; and formed of a substance entirely adapted to the feeble state of incipient vegetation: it was an uniform plain, every where covered with verdure; without mountains, without seas, or the smallest inequalities. It had no difference of seasons, for its equator was in the plain of the ecliptic, or, in other words, it

on this subject, who has united observation with theory.

With

it turned directly opposite to the sun, so that it enjoyed one perpetual and luxuriant spring. However, this delightful face of nature did not long continue in the same state, for, after a time, it began to crack and open in fissures: a circumstance which always succeeds when the sun exhales the moisture from rich or marshy situations. The crimes of mankind had been for some time preparing to draw down the wrath of Heaven; and they, at length, induced the Deity to defer repairing these breaches in nature. Thus the chasms of the earth every day became wider, and, at length, they penetrated to the great abyss of waters; and the whole earth, in a manner, fell in. Then ensued a total disorder in the uniform beauty of the first creation, the terrene surface of the globe being broken down: as it sunk the waters gushed out in its place; the deluge became universal; all mankind, except eight persons, were destroyed, and their posterity condemned to toil upon the ruins of desolated nature.

'It only remains to mention the manner in which he relieves the earth from this universal wreck, which would seem to be as difficult as even its first formation. "These great masses of earth falling into the abyss, drew down with them vast quantities also of air; and by dashing against each other, and breaking into small parts by the repeated violence of the shock, they, at length, left between them large cavities filled with nothing but air. These cavities naturally offered a bed to receive the influent waters; and in proportion as they filled, the face of the earth became once more visible. The higher parts of its broken surface, now become the tops of mountains, were the first that appeared; the plains soon after came forward, and, at length, the whole globe was delivered from the waters, except the places in the lowest situations; so that the ocean and the seas are still a part of the ancient abyss that have not had a place to return to. Islands and rocks are fragments of the earth's former crust; kingdoms and continents are larger masses of its broken substance; and all the inequalities that are to be

found

With reſpect to the form of the earth; it is now ſcarcely neceſſary to mention, that it is nearly round;

found on the ſurface of the preſent earth, are owing to the accidental confuſion into which both earth and waters were then thrown."

'The next theoriſt was Woodward, who, in his Eſſay towards a Natural Hiſtory of the Earth, which was only deſigned to precede a greater work, has endeavoured to give a more rational account of its appearances; and was, in fact, much better furniſhed for ſuch an undertaking than any of his predeceſſors, being one of the moſt aſſiduous naturaliſts of his time. His little book, therefore, contains many important facts, relative to natural hiſtory, although his ſyſtem may be weak and groundleſs.

'He begins by aſſerting that all terrene ſubſtances are diſpoſed in beds of various natures, lying horizontally one over the other, ſomewhat like the coats of an onion; that they are replete with ſhells, and other productions of the ſea: theſe ſhells being found in the deepeſt cavities, and on the tops of the higheſt mountains. From theſe obſervations, which are warranted by experience, he proceeds to obſerve, that theſe ſhells and extraneous foſſils are not productions of the earth, but are all actual remains of thoſe animals which they are known to reſemble; that all the beds of the earth lie under each other, in the order of their ſpecific gravity; and that they are diſpoſed as if they had been left there by ſubſiding waters. All theſe aſſertions he affirms with much earneſtneſs, although daily experience contradicts him in ſome of them; particularly we find layers of ſtone often over the lighteſt ſoils, and the ſofteſt earth under the hardeſt bodies. However, having taken it for granted, that all the layers of the earth are found in the order of their ſpecific gravity, the lighteſt at the top, and the heavieſt next the center, he conſequently aſſerts, and it will not improbably follow, that all the ſubſtances of which the earth is compoſed were once in an actual ſtate of diſſolution. This univerſal diſſolution he takes to have happened at the time of the flood. He ſuppoſes that at that time a body of water, which was then in

round; a circumstance, however, which, though now so universally known, remained undiscovered for many

in the center of the earth, uniting with that which was found on the surface, so far separated the terrene parts as to mix all together in one fluid mass; the contents of which afterwards sinking according to their respective gravities, produced the present appearances of the earth. Being aware, however, of an objection that fossil substances are not found dissolved, he exempts them from this universal dissolution, and, for that purpose, endeavours to shew that the parts of animals have a stronger cohesion than those of minerals; and that, while even the hardest rocks may be dissolved, bones and shells may still continue entire.

' So much for Woodward; but of all the systems which were published respecting the earth's formation, that of Whiston was most applauded, and most opposed. Nor need we wonder; for being supported with all the parade of deep calculation, it awed the ignorant, and produced the approbation of such as would be thought otherwise, as it implied a knowledge of abstruse learning, to be even thought capable of comprehending what the writer aimed at. In fact, it is not easy to divest this theory of its mathematical garb; but those who have had leisure, have found the result of our philosopher's reasoning to be thus. He supposes the earth to have been originally a comet; and he considers the history of the creation, as given us in scripture, to have its commencement just when it was, by the hand of the Creator, more regularly placed as a planet in our solar system. Before that time, he supposes it to have been a globe without beauty or proportion; a world in disorder; subject to all the vicissitudes which comets endure; some of which have been found, at different times, a thousand times hotter than melted iron; at others, a thousand times colder than ice. These alternations of heat and cold, continually melting and freezing the surface of the earth, he supposes to have produced, to a certain depth, a chaos entirely resembling that described by the poets, surrounding the solid contents of the earth, which still continued unchanged

many thousand years. That its form is spherical, was first conjectured from the curved line which bounds

unchanged in the midst, making a great burning globe of more than two thousand leagues in diameter. This surrounding chaos, however, was far from being solid: he resembles it to a dense though fluid atmosphere, composed of substances mingled, agitated, and shocked against each other; and in this disorder he describes the earth to have been just at the eve of creation.

'But upon its orbit's being then changed, when it was more regularly wheeled round the sun, every thing took its proper place; every part of the surrounding fluid then fell into a situation, in proportion as it was light or heavy. The middle, or central part, which always remained unchanged, still continued so, retaining a part of that heat which it received in its primæval approaches towards the sun; which heat, he calculates, may continue for about six thousand years. Next to this fell the heavier parts of the chaotic atmosphere, which serve to sustain the lighter: but as in descending they could not entirely be separated from many watery parts, with which they were intimately mixed, they drew down a part of these also with them; and these could not mount again after the surface of the earth was consolidated: they, therefore, surrounded the heavy first descending parts, in the same manner as these surround the central globe. Thus the entire body of the earth is composed internally of a great burning globe: next which is placed an heavy terrene substance, that encompasses it; round which also is circumfused a body of water. Upon this body of water, the crust of earth on which we inhabit is placed: so that, according to him, the globe is composed of a number of coats, or shells, one within the other, all of different densities. The body of the earth being thus formed, the air, which is the lightest substance of all, surrounded its surface; and the beams of the sun darting through, produced that light which, we are told, first obeyed the Creator's command.

'The whole œconomy of the creation being thus adjusted, it only remained to account for the risings and depressions on the surface of the earth, with the other seeming irregularities of

bounds the earth's shadow in lunar eclipses. We have a still plainer proof of its rotundity, from the appearance

of its present appearance. The hills and vallies are consider-ed by him as formed by their pressing upon the internal fluid, which sustains the outward shell of earth, with greater or less weight: those parts of the earth which are heaviest, sink into the subjacent fluid more deeply, and become vallies: those that are lightest, rise higher upon the earth's surface, and are called mountains.

'Such was the face of nature before the deluge; the earth was then more fertile and populous than it is at present; the life of man and animals were extended to ten times its present duration; and all these advantages arose from the superior heat of the central globe, which ever since has been cooling. As its heat was then in full power, the genial principle was also much greater than at present; vegetation and animal increase were carried on with more vigour; and all nature seemed teeming with the seeds of life. But these physical advantages were only productive of moral evil; the warmth which invigorated the body encreased the passions and appetites of the mind; and, as man became more powerful, he grew less innocent. It was found necessary to punish this depravity; and all living creatures were overwhelmed by the deluge in universal destruction.

'This deluge, which simple believers are willing to ascribe to a miracle, philosophers have been long desirous to account for by natural causes: they have proved that the earth could never supply from any reservoir towards its center, nor the atmosphere by any discharge from above, such a quantity of water as would cover the surface of the globe to a certain depth over the tops of our highest mountains. Where, therefore, was all this water to be found? Whiston has found enough, and more than a sufficiency, in the tail of a comet; for he seems to allot comets a very active part in the great operations of nature.

'He calculates with great seeming precision, the year, the month, and the day of the week on which this comet (which has paid the earth some visits since, though at a kinder distance) involved

appearance of objects on the surface of the earth, but still more remarkably on that of the sea. As we

involved our globe in its tail. The tail he supposed to be a vapourous fluid substance, exhaled from the body of the comet, by the extreme heat of the sun, and increasing in proportion as it approached that great luminary. It was in this that our globe was involved at the time of the deluge; and, as the earth still acted by its natural attraction, it drew to itself all the watery vapours which were in the comet's tail; and the internal waters being also at the same time let loose, in a very short space the tops of the highest mountains were laid under the deep.

The punishment of the deluge being thus completed, and all the guilty destroyed, the earth, which had been broken by the eruption of the internal waters, was also enlarged by it; so that upon the comet's recess, there was found room sufficient in the internal abyss for the recess of the superfluous waters; whither they all retired, and left the earth uncovered, but in some respects changed, particularly in its figure, which, from being round, was now become oblate. In this universal wreck of nature Noah survived, by a variety of happy causes, to re-people the earth, and to give birth to a race of men slow in believing ill-imagined theories of the earth.

After so many theories of the earth, which had been published, applauded, answered, and forgotten, M. Buffon ventured to add one more to the number. This philosopher was in every respect better qualified than any of his predecessors for such an attempt, being furnished with more materials, having a brighter imagination to find new proofs, and a better style to cloath them in. However, if one so ill qualified as I am may judge, this seems the weakest part of his admirable work; and I could wish that he had been content with giving us facts instead of systems; that, instead of being a reasoner, he had contented himself with being merely an historian.

He begins his system by making a distinction between the first part of it and the last; the one being founded only on conjecture, the other depending entirely upon actual observation.

we depart from objects on the ocean, they seem to subside gradually below the visible horizon. Ships at

The latter part of his theory may, therefore, be true, though the former should be found erroneous.

The planets, says he, and the earth among the number, might have been formerly (he only offers this as conjecture) a part of the body of the sun, and adherent to its substance. In this situation, a comet falling in upon that great body might have given it such a shock, and so shaken its whole frame, that some of its particles might have been driven off like streaming sparkles from red hot iron; and each of these streams of fire, small as they were in comparison of the sun, might have been large enough to have made an earth as great, nay many times greater than ours. So that in this manner the planets, together with the globe which we inhabit, might have been driven off from the body of the sun by an impulsive force: in this manner also they would continue to recede from it for ever, were they not drawn back by its superior power of attraction; and thus, by the combination of the two motions, they are wheeled round in circles.

Being in this manner detached at a distance from the body of the sun, the planets, from having been at first globes of liquid fire, gradually became cool. The earth also having been impelled obliquely forward, received a rotatory motion upon its axis at the very instant of its formation; and this motion being greatest at the equator, the parts there acting against the force of gravity, they must have swollen out, and given the earth an oblate or flatted figure.

As to its internal substance, our globe having once belonged to the sun, it continues to be an uniform mass of melted matter, very probably vitrified in its primæval fusion. But its surface is very differently composed. Having been in the beginning heated to a degree equal to, if not greater, than what comets are found to sustain, like them it had an atmosphere of vapours floating round it, and which, cooling by degrees, condensed and subsided upon its surface. These vapours formed, according to their different densities, the earth, the water, and the

at a distance on the water are not visible in their hulls; at a greater distance, their mainsails disappear;

the air; the heavier parts falling first, and the lighter remaining still suspended.

Thus far our philosopher is, at least, as much a system-maker as Whiston or Burnet; and, indeed, he fights his way with great perseverance and ingenuity through a thousand objections that naturally arise. Having, at last, got upon the earth, he supposes himself on firmer ground, and goes forward with greater security. Turning his attention to the present appearance of things upon this globe, he pronounces from the view that the whole earth was at first under water. This water he supposes to have been the lighter parts of its former evaporation, which, while the earthy particles sunk downwards by their natural gravity, floated on the surface, and covered it for a considerable space of time.

"The surface of the earth," says he *, "must have been in the beginning much less solid than it is at present; and, consequently, the same causes, which at this day produce but very slight changes, must then, upon so complying a substance, have had very considerable effects. We have no reason to doubt but that it was then covered with the waters of the sea; and that those waters were above the tops of our highest mountains, since, even in such elevated situations, we find shells and other marine productions in very great abundance. It appears also that the sea continued for a considerable time upon the face of the earth: for as these layers of shells are found so very frequent at such great depths, and in such prodigious quantities, it seems impossible for such numbers to have been supported all alive at one time; so that they must have been brought there by successive depositions. These shells also are found in the bodies of the hardest rocks, where they could not have been deposited all at once, at the time of the deluge, or at any such instant revolution; since that would be to suppose, that all the rocks in which they are found were, at that instant, in a state of disso-

* Theorie de la Terre, vol. i. p. 111.

pear; and at a greater ſtill, their topſails; which could not be, if they ſailed on a plain. But that the earth is really globular was at length practically demonſtrated by the adventurous project of ſailing round it, which has ſeveral times been effected.

This fact being premiſed, let us conſider in what manner the known laws of nature were likely to act upon a maſs of materials ſuch as enter into the compoſition of this globe.

The firſt principle of the law of gravitation is, that the conſtituent particles of all bodies attract each

lution, which would be abſurd to aſſert. The ſea, therefore, depoſited them where ever they are now to be found, and that by ſlow and ſucceſſive degrees.

"It will appear, alſo, that the ſea covered the whole earth, from the appearance of its layers, which lying regularly one above the other, ſeem all to reſemble the ſediment formed at different times by the ocean. Hence, by the irregular force of its waves, and its currents driving the bottom into ſand-banks, mountains muſt have been gradually formed within this univerſal covering of waters; and theſe ſucceſſively raiſing their heads above its ſurface, muſt, in time, have formed the higheſt ridges of mountains upon land, together with continents, iſlands, and low grounds, all in their turns. This opinion will receive additional weight by conſidering, that in thoſe parts of the earth where the power of the ocean is greateſt, the inequalities on the ſurface of the earth are higheſt: the ocean's power is greateſt at the equator, where its winds and tides are moſt conſtant; and, in fact, the mountains at the equator are found to be higher than in any other part of the world. The ſea, therefore, has produced the principal changes in our earth: rivers, volcanoes, earthquakes, ſtorms, and rain, having made but ſlight alterations, and only ſuch as have affected the globe to very inconſiderable depths."

Goldsmith's *Hiſtory of the Earth and Animated Nature*, Vol. I. p. 22, &c.

other mutually, whence arife their common centers of gravity. Hence all fluids affume a fpherical form, from the particles mutually attracting each other; and no bodies but fluids being capable of obeying the laws of gravitation, fo as to become fpherical, it is prefumed that the earth was originally in a fluid ftate. The earth revolves round its center, and the centrifugal force increafes in proportion to the diftance from the axis of motion; all bodies, therefore, revolving round their axis in a ftate of fluidity, will neceffarily depart from the fpherical form, and affume that of an oblate fpheroid. Such, by actual menfuration, is found to be the form of the earth; and this is alfo demonftrated, by aftronomical obfervations, to be the cafe with all the other planets. It is therefore highly probable, that all thefe bodies were originally fluid, and only departed in fome meafure from the fpherical form, in confequence of a revolution on their axis.

It is not natural or eafy to fuppofe, that the earth and planets have, fince their exiftence, been reduced, by any folvent principle, from a folid to a fluid ftate. It is much more obvious to believe, that fuch was their ftate at their firft creation. It follows of confequence, that they had a beginning, and have not exifted from eternity, as fome fantaftical writers have been inclined to imagine.

If fuch was the original ftate of the earth, it follows, that it was at firft abfolutely unfit for animal and vegetable life; and, therefore, thefe muft have been after-creations. This account, it is obfervable, agrees admirably with the Mofaic account of the

creation, as well as with the opinions of the most ancient philosophers, historians, poets, &c. that is, with the traditions of the first ages.

It is the opinion of Mr. Whitehurst, that the component parts of the earth, at its first formation, existed in a state of actual solution, and that they subsided partly into solid bodies, and partly into fluids, by the mutual action of these particles upon each other.

We have seen that there exists between different particles of matter what is called elective or chemical attraction, by which substances having certain properties in common are disposed to unite; and by the combinations thus formed (whether by an immediate act of omnipotence, or whether by some more gradual process) the suspension of the component parts of the chaotic mass would be effectually destroyed, and bodies would approach towards their center of gravity in proportion to their respective densities. That the laws of elective attraction have prevailed in the formation of the earth is evident from the sameness of quality which is observed in different strata of minerals.

It has been, I think, demonstrated, that the presence of heat or fire is the efficient cause of fluidity. When the permanently elastic fluids, therefore, which constitute the atmosphere, assumed their aeriform state, and rose from the chaotic mass, a great quantity of heat must have become latent, while the remaining substances, from which the heat was abstracted, must have been considerably cooled, and it might, therefore, be expected, that

those

those kinds of matter, which had least attraction for heat, would assume a solid form; while others, whose attraction for that substance was intermediate, would remain in the state of common fluids. It is, therefore, perfectly agreeable to sound philosophy to suppose, that the abstraction of a considerable quantity of caloric, or the matter of fire, from the chaotic mass, would effectually destroy its fluidity, and would almost instantly produce all the different mineral substances, which are observed in the bowels of the earth. Not that we are under any necessity of believing, that the whole internal substance of the earth exists at this hour as it existed when creation was completed. There are a variety of processes going on continually in the interior parts of the globe, beside those more sudden and violent changes, which have been produced by earthquakes, floods, and volcanoes.

By the subsiding of the denser and more solid bodies, a considerable portion of the fluid matter would be left in a separate state, and would form large masses, or oceans of water.

With respect to the formation of islands, nothing more was necessary than the unequal and irregular subsiding of the different parts of matter, which may have happened from a variety of causes; from the effects of elective attraction and crystallization; from the motion of the earth, and the flux and reflux of the tides. The latter cause would necessarily remove the solid masses, as they were formed, from place to place, till these solid masses, meeting with others, or increasing their bulk by their action

upon congenial particles, would, from their increaſed gravity and denſity, at length become ſtationary. Thus the ſurface of the earth is all irregular, and an iſland is no other than a hill or mountain, the adjacent vallies of which are filled with water. Some iſlands, however, we know, are of more recent origin. Some have been thrown up by volcanic eruptions; and ſome have apparently been formed by that extraordinary inſect which produces rocks of coral. The iſlands Delos and Rhodes are ſaid to have *grown* out of the ſea. Pliny mentions a number of other iſlands, which were produced by ſubterraneous fires. In 1628, one of the iſlands of the Azores roſe up out of the bottom of the ſea, which in that place was one hundred and ſixty fathoms deep; and this iſland, which is three leagues long, one league and an half broad, and three hundred and ſixty feet above the level of the water, roſe in fifteen days *.

On the 20th of November, 1720, a ſubterraneous fire burſt out of the ſea near Tercera, one of the Azores, which threw up ſuch a quantity of ſtones, in the ſpace of thirty days, as formed an iſland two leagues in diameter, and nearly circular †.

The Iſle of Sheppey contains a great variety of foſſil bodies, as well animal as vegetable, which evidently prove it to be an aſſemblage of adventitious matter.

* Sir William Hamilton's Obſervations on Veſuvius and Ætna.

† Philoſophical Tranſactions, quoted by Whitehurſt.

In

In every instance upon record, the fragments of sea shells are infinitely more numerous than the bones and teeth of fish. The latter too are but seldom deposited in any other matter than in beds of sand and gravel, and not in the solid beds of lime-stone, as the shells of fish generally are, even to the depth of many hundred yards, and dispofed throughout the whole extent of the strata *.

There is no occasion to suppose, that the whole surface of the earth was at once rendered habitable. From the scripture account we have reason to believe, that only a very small part of it was inhabited for a long series of time, *viz.* the regions about the Euphrates, supposed to constitute the Garden of Eden. Here the terrestrial animals were chiefly assembled, while the marine animals were dispersed through the great abyss of waters; and, from the extreme fecundity of those animals, they would, in a very short space of time "replenish the waters" from pole to pole. If, therefore, we suppose (as is most probable) that the greater part of the earth was gradually forming itself according to the laws of nature and creation, in other words, according to the usual processes of attraction and combination, it is easy to conceive, that a part of these animals, especially those which are least active, would be gradually intombed in the increasing mass, and this will account for the great quantities of the exuviæ and bones of marine animals, especially shell fish, which are found in beds of lime-stone, gravel, &c. even on the tops of mountains.

* Whitehurst, p. 44.

We

We ſhall ceaſe to be aſtoniſhed at the immenſe quantities of ſhells, which are thus found imbedded in the earth, if we only conſider the amazingly prolific nature of theſe animals. It is not uncommon to take away a bed of theſe ſhell fiſh ſeveral fathoms in thickneſs; and, though the places whence they are removed appear entirely exhauſted, yet in the enſuing ſeaſon there ſhall be as many found in all theſe places as there were before *.

The bones or teeth of fiſh, Mr. Whitehurſt affirms, as far as his knowledge extends, have never been found mixed with ſhells in the ſolid ſubſtance of lime-ſtone.

That at different periods the earth muſt have ſuffered very violent convulſions and diſcerptations of the ſolid parts, we may reaſonably conclude from the rugged and uncouth appearance of many of the mountainous parts of the world. We ſee rocks in ſome places torn aſunder, or, in appearance cut with a ſaw. Mr. Whitehurſt remarks, that at Stafford and Newport, in Shropſhire, there are detached blocks of Corniſh moor-ſtone, or granite, of conſiderable magnitude, though no ſuch ſtratum is known to exiſt nearer than Cornwall. It is fair, therefore, to conclude, that they have been thrown there by ſome violent commotion or ſubterraneous convulſion.

To the general deluge, that fact recorded with ſo much preciſion in the writings of Moſes, and confirmed by the traditions of every nation, we muſt

* Whitehurſt, p. 47.

attribute

attribute much of the irregularities of the earth's ſurface. It would in ſome inſtances have the effect of reducing great maſſes of matter to a ſecond ſtate of ſolution. Many eminences would be levelled, and ſome of the vallies would be filled up. Some parts, which before were ſea, might receive ſuch an acceſſion of foreign matter as to fill up their beds, and on the ſubſiding of the waters to preſent to the eye a vaſt level plain. Thoſe elevations, on the contrary, which conſiſted of ſolid maſſes of the harder ſtones, would have the lighter portions of earth waſhed away from their baſes, and their height would receive a proportional increaſe. If pit coal, indeed, is of vegetable origin, it is difficult to account for the depoſition of ſuch a quantity of vegetable matter beneath the ſurface of the earth, on any other hypotheſis than that of a deluge; and though much of the exuviæ of ſhell-fiſh might be involved in the firſt ages ſucceeding the creation, in the manner Mr. Whitehurſt ſuppoſes, much greater quantities would be inhumed at the deluge. The other animal matters found in a foſſil ſtate, particularly the horns, ſkeletons, and bones of animals, which are much larger than any now found upon the earth, can only be accounted for upon this hypotheſis. Such are thoſe mentioned by Buffon, which were dug up in America, near the river Ohio, a ſingle tooth of which, belonging to a large row, weighed upwards of eleven pounds, and a ſingle thigh bone was upwards of four feet in length. In the year 1783, a ſkeleton of an immenſe animal of the deer kind was found on an eſtate belonging

to

to Dr. Percy, Bishop of Dromore. It was dug out of a marle pit, under a peat moss, and was found surrounded by shells and other marine productions. The horns were seven feet and one inch in height, the length of the skull nearly two feet, the breadth of the forehead nearly a foot, and the bones of an enormous size. In Siberia, in America, and even in England, the bones and teeth of the elephant, hippopotamus, and other animals, which never have existed in those climates, have been found, and even these were larger than those of any such animals now existing.

To the deluge, therefore, much of the present inequalities of the earth may be rationally attributed. But there are other causes which may have operated both before and since. It is a fact, which will scarcely admit of dispute, that volcanic eruptions were much more frequent in the early ages of the world than at present; the vestiges of volcanoes, and, even the exhausted craters, are often found, where there is now not the least appearance of subterraneous fire. This fact is also easily accounted for on philosophical principles. The imperfect, and, if I may so speak, accidental mixture of different bodies, would in many cases produce spontaneous inflammation in the early ages of the world, whereas, as the earth grows older, these materials must be exhausted, or rather formed into other combinations. Many mountains, we know, are of volcanic origin, and therefore many of them of a date long posterior to the æra of creation.

Such

Such appears to be the moſt rational account of the ſtructure of the earth, as far as we are warranted by actual experiment, or well authenticated obſervation. The ſucceeding chapters of this book will ſerve to explain more ſatisfactorily the different appearances of different portions of the globe. I ſhall therefore proceed, without further digreſſion, to treat more particularly of mountains, volcanoes, and the other phenomena more immediately connected with this branch of natural hiſtory.

## Chap. XLIV.

### MOUNTAINS.

*Distinction between Hills and Mountains.—Mountains primæval or secondary.—Granite Mountains only supposed in general primæval.—Some lime-stone Mountains primæval.—Alluvial Mountains.—Entire and stratified Mountains.—Mountains homogeneous and heterogeneous.—Confused Mountains.—Volcanic Mountains.—Height of Mountains, how measured.—Computed Heights of the most remarkable Mountains.—Line of Congelation in different Parts of the World.*

ELEVATIONS, consisting chiefly of clay, sand, or gravel, are called hills. Those which consist chiefly of stone are called mountains. Mountains are divided into primæval, that is, of equal date with the formation of the globe, and secondary or alluvial. Among primæval, those of granite hold the first place. The highest mountains and most extensive ridges throughout the globe are of that kind; as the Alps and Pyrennees, in Europe; the Altuischan, Uralian, and Caucasus, in Asia; and the Andes, in America. The highest of them never contain metallic ores; but some of the lower contain ores of copper and tin. The granite next the ore always abounds in mica. Petrifactions are never found in these primæval mountains.

That the formation of these mountains preceded that of vegetables and animals, is justly inferred from their containing no organic remains, either in the

form of petrifaction or impression. Naturalists are agreed, that granites were formed by crystallization. This operation probably took place after the formation of the atmosphere, and the gradual excavation of the bed of the ocean, when the dry land appeared. For, as was remarked in the preceding chapter, by means of the separation of the aeriform fluids, which constitute the atmosphere, the evaporation of part of the water into the atmosphere, and the gradual retreat of the remainder, the various species of earths, before dissolved or diffused through this mighty mass, were disposed to coalesce, and among these the siliceous must have been the first, as it is the least soluble; but as the siliceous earth has an affinity to the other earths with which it was mixed, some of these must have united in various proportions, and thus have formed, in distinct masses, the felt spar, shoerl, and mica, which compose the granite. Calcareous earth enters very sparingly into the composition of this stone; but as it is found in shoerl, which is frequently a component part of granite, it follows that it must be one of the primitive earths, and not entirely derived from marine exuviæ, as some have supposed. Quartz can never be supposed to be a product of fire; for in a very low heat it bursts, cracks, and loses its transparency, and in the highest degree of heat that we can produce, is infusible, so that in every essential point it is different from glass, to which some have compared it. As granite contains earths of every genus, we may conclude, that all the simple earths are original. This, however, is no proof that they are in reality simple

ſimple and uncompounded of other principles; but they muſt be conſidered as ſuch in the preſent ſtate of our knowledge. Though water undoubtedly dates from creation, yet late experiments have ſhewn it to be a compound, as was formerly ſtated.

Mountains, which conſiſt of lime-ſtone or marbles of a granular or ſcaly texture, and not diſpoſed in ſtrata, ſeem alſo to have preceded the creation of animals, for no organic traces are found in them. Some of thoſe, which conſiſt of argillaceous ſtones, and ſome of the ſiliceous, contain alſo no organic remains. Theſe often conſiſt of parallel ſtrata of unequal thickneſs, and the lower are harder and leſs thick than the upper, and therefore ſeem to have been formed earlier than the upper.

Alluvial mountains are evidently of poſterior formation, as they contain petrifactions and other veſtiges of organic ſubſtances, and theſe are always ſtratified.

Mountains, as to ſtructure, are entire, ſtratified, and confuſed. Entire mountains are formed of huge maſſes of ſtone, without any regular fiſſures, and are moſtly homogeneous. They conſiſt chiefly of granite, ſometimes gneiſs *, ſchiſtus, flag-ſtone, ſand-ſtone, lime-ſtone, gypſum, porphyry or trapp. Some in Sweden and Norway conſiſt of iron ore.

The ſtratified mountains are thoſe whoſe maſs is regularly divided by joints or fiſſures; theſe are called horizontal, riſing, or dipping. Homogenous ſtra-

* A rock conſiſting of mica, lapis ollaris, and quartz.

tified

tified mountains conſiſt chiefly of ſtones of the argillaceous genus, or of the fiſſile compound ſpecies of the ſiliceous genus, as metallic rock; ſometimes of lime-ſtone of a granular or ſcaly texture, in which no animal veſtiges appear. This lime-ſtone repoſes on the argillaceous or ſiliceous ſtrata: ſometimes the argillaceous are covered with maſſes of granite, ſometimes of lava. Theſe mountains, particularly thoſe of gneiſs, metallic rock, and horn-ſtone, are the chief ſeat of metallic ores. When covered with lime-ſtone, the ore is generally between the lime-ſtone and the argillaceous ſtones. Theſe ores run in veins, not in ſtrata. Petrifactions are found upon, but not in, theſe mountains.

Heterogeneous, or compound ſtratified mountains, conſiſt of alternate ſtrata of various ſpecies of ſtones, earths, ſands, &c. The lime-ſtone here is always of the laminar, and not of the granular or ſcaly kind, and when it contains any ore, it is placed between its laminæ. Stones of the ſiliceous genus ſeldom form ſtrata in theſe mountains, except lavas; but the ſtrata are frequently interrupted by ſiliceous maſſes, as jaſper, porphyry, &c. Coal, bitumen, petrifactions, and organic impreſſions, are found in theſe mountains, alſo ſalts and calamine.

There are other mountains, which cannot properly be called ſtratified, as they conſiſt only of three immenſe maſſes, the loweſt granite, the middle argillaceous, and the upper lime-ſtone. Metallic ores are found in the argillaceous part, or between it and the lime-ſtone.

Confuſed mountains conſiſt of ſtones heaped together without order, their interſtices filled with clay, ſand, and mica. They ſcarcely ever contain any ore.

Beſides theſe, there are many mountains in different parts of the world, which derive their origin from volcanoes; but of theſe it will be neceſſary to treat in the ſucceeding chapter.

The height of mountains is uſually calculated by means of the barometer, upon the principles already explained. For this purpoſe two columns of mercury, or barometers, are provided, and one is kept at the foot of the mountain while the other is carried to its ſummit. The degree of heat, if not equal, is reduced by calculation to an equality, and for this purpoſe a thermometer is attached to each of the barometers. The degree of heat, to which both are reduced, is commonly 55°. If, however, either of the barometers ſtands at thirty inches, and the annexed thermometer at 55°, no reduction is to be made in the degrees indicated by that barometer; but if either of them is at 30°, and the thermometer below 55°, we muſt add the expanſion the mercury in the barometer would have experienced at the heat of 55°. If the heat ſhould, on the contrary, be above 55°, we muſt ſubſtract the degree of expanſion which it gains by that heat. Every degree of Farenheit's ſcale produces an expanſion of c0.304 of the barometrical inch, when the barometer is at 30; when, therefore, the thermometer is at 11° below or above 55°, we muſt add in the former, or ſubſtract in the latter

latter caſe, eleven times that number from the barometrical height. In the ſame manner it may be calculated, whatever is the height of the barometer. When this matter is aſcertained, the height is eaſily found by comparing the two barometers, and calculating the denſity of the air in the higher regions according to the principles of geometrical progreſſion.

The higheſt mountains are thoſe which are ſituated at or near the equator; and the Andes are generally allowed to be the higheſt of theſe. Catopaxi, one of the Andes, which was meaſured by Ulloa and the French academicians, was found to be rather more than three miles above the level of the ſea; whereas the higheſt point of the Alps is not above a mile and a half. Mount Caucaſus approaches neareſt to the height of the Andes of any of the Aſiatic mountains. The Pike of Teneriff, which has been ſo much celebrated, is about a mile and a half in height. It is an extraordinary circumſtance, that the moon, which is a body ſo much ſmaller than our earth, ſhould ſo greatly exceed it in the irregularities of its ſurface; ſome of the mountains in that planet being calculated to exceed nine miles in height.

The line of congelation, or perpetual froſt, on mountains, is calculated at 15,400 feet, at or near the equator; at the entrance of the temperate zone, at 13,428; on Teneriffe, at 1,000; in Auvergne (lat. 45.) 6,740; with us (lat. 52.) 5,740. On the Andes, vegetation ceaſes at 14,697 feet; and on

the Alps, at 9,585. The air is ſo dry in theſe elevated ſituations, that M. D'Arcel obſerved, that on the Pic de Midi, one of the Pyrenees, ſalt of tartar remained dry for an hour and a half, though it immediately moiſtened in the ſame temperature at the bottom of the mountain.

## CHAP. XLV.

### VOLCANOES.

*General Observations on Volcanoes.—Their Connection with the Sea.—Immense Force of subterraneous Fires exemplified in various Instances.—Theory of Volcanoes.—Great Depth.—Traces of Volcanoes in different Parts of the World.—Description of Ætna.—Eruption of Vesuvius, in* 1794.

VOLCANOES are peculiar to no climate, and have no necessary or regular connection with any other mountains, but seem to have some with the sea, for they are generally in its neighbourhood. It has been remarked by those who have observed them, that volcanoes often throw out matters which belong to the sea, as the relics of fish, sea-weed, and often immense quantities of sea-water itself. Sir William Hamilton observes, in the Philosophical Transactions for the year 1776, "that the operations of Vesuvius are very capricious and uncertain, except that the smoke increases considerably and constantly when the sea is agitated, and the wind blows from that quarter."

There are ancient extinguished volcanoes, it is true, which are inland; but this is only one of many proofs that the sea covered those countries at some remote period. Volcanic mountains are of all heights; some so low as four hundred and fifty feet, as that of Tanna; Vesuvius is three thousand six hundred feet high, and Ætna eleven thousand.

They in general form lofty ſpires, and the volcano itſelf is internally ſhaped like an inverted cone, placed on a broader baſis. This cone is called the crater, or bowl, and through it the lava generally paſſes, though ſometimes it burſts through the ſides, and even proceeds occaſionally from the bottom of the mountain. Sometimes the crater falls in and is effaced, ſometimes, in extinguiſhed volcanoes, it is filled with water. Sub-marine volcanoes have been obſerved, and from theſe ſome iſlands have derived their origin. Volcanic fires, taking place at the bottom of the ocean, would frequently, by the expanſive force of the ſteams which are generated, elevate thoſe parts which were once at the bottom of the deep, and overflow thoſe which were habitable earth. It is very probably conjectured, as was noticed in a preceding chapter, that ſubterraneous convulſions operated more powerfully in the early ages of the world than at any later period; and indeed ſuch an hypotheſis is ſupported by the moſt probable reaſoning, ſince we may well conceive, that at the firſt conſolidation of the earth, much heterogeneous matter would be included in the different maſſes, which might produce more frequent fermentations than at any after periods, when theſe have been, if I may ſo expreſs it, purged off by frequent eruptions, and in many parts, perhaps, rectified and aſſimilated by ſlow and ſecret proceſſes in the bowels of the earth. But hiſtory was not cultivated till a very late period, and the moſt eventful ages of nature have paſſed unrecorded.

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The force of ſubterraneous fires, or rather of the ſteam which is generated by them, is ſo great, that conſiderable rocks have been projected by Veſuvius to the diſtance of eight miles. A ſtone was once thrown from the crater of that volcano twelve miles, and fell upon the Marquis of Lauro's houſe at Nola, to which it ſet fire. One alſo, which meaſured twelve feet in height and forty-five in circumference, was carried, in 1767, by the projectile force of the ſteam, a quarter of a mile from the crater. In an eruption of Ætna, a ſtone, fifteen feet long, was ejected from the crater to the diſtance of a mile, and buried itſelf eight feet deep in the ground.

A volcano broke forth in Peru, in 1600, accompanied with an earthquake, and the ſand and aſhes which were ejected covered the fields ninety miles one way and one hundred and twenty another. Dreadful thunders and lightning were heard and ſeen for upwards of ninety miles round Araquapa during this eruption, which ſeemed to denote ſome connection between the electric matter and theſe volcanic fires *; and this fact is ſtrongly confirmed by the very accurate obſervations of Sir William Hamilton, which I ſhall afterwards have occaſion to notice more at large.

Both the inſide of the crater and the baſis of many volcanoes conſiſt of lava, either entire or decompoſed, nearly as low as the level of the ſea, but they finally reſt either on granite, as in Peru, or ſchiſtus, as the extinguiſhed volcanoes of Heſſe and Bohemia, or on lime-ſtone, as thoſe of Sileſia,

* Dr. Hooke's poſthumous Works, p. 304.

Mount Vesuvius, &c. No ore is found in these mountains, except that of iron, of which lava contains from twenty to twenty-five parts in the hundred, and some detached fragments of the ores of copper, antimony, and arsenic. Vesuvius ejected, from the year 1779 to 1783, 309,658,161 cubic feet of matter of different kinds; we must therefore conclude the seat of these fires to be several miles, perhaps hundreds of miles, below the level of the sea; and as iron makes from one-fourth to one-fifth of these ejections, we may infer that the internal parts of the earth abound much in this metal.

The origin of these subterraneous fires is not easily explained. Iron filings mixed with powdered sulphur, and the whole moistened with water into a paste, we have formerly seen, will swell, become hot, and, if the quantity is considerable, will throw out a blue flame. It is a mixture of this kind which is used for making an artificial earthquake, for such a quantity of inflammable gas is produced during the fermentation, that if the mass is buried in the earth, the gas will force a passage for its escape, and exhibit, on a small scale, the phenomena of an earthquake. M. Lemery seems to have been the first person who illustrated, in this manner, the origin of volcanic fires and earthquakes. He mixed twenty-five pounds of iron filings with an equal weight of sulphur, and having made them into a paste with the addition of water, he put them into a pot, covered them with a cloth, and buried them a foot under ground. In about eight or nine hours time the earth swelled, became warm, and cracked,

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and hot ſulphureous vapours were perceived *. Now, large beds of martial pyrites, which are natural combinations of iron and ſulphur, are known to exiſt in different parts of the earth; the only diffi-

* That part of this experiment (ſays Biſhop Watſon) which relates to the production of fire, by the fermentation of iron filings and ſulphur when made into a paſte, has been frequently repeated ſince the time of Mr. Lemery. I myſelf have made it more than once, but I have nothing material to add to his account, except that the flame, when the experiment is made in the open air, is of very ſhort duration; and that the whole maſs, after the extinction of the flame, continues at intervals, for a longer or ſhorter time, according to its quantity, to throw out ſparks; and that a ladle full of the ignited maſs, being dropped down from a conſiderable height, deſcends like a ſhower of red-hot aſhes, much reſembling the paintings of the eruptions of Mount Veſuvius, which may be ſeen at the Britiſh Muſeum. It has been obſerved, that large quantities of the materials are not requiſite to make the experiment ſucceed, provided there be a due proportion of water: half a pound of ſteel filings, half a pound of flowers of brimſtone, and fourteen ounces of water, will, when well mixed, acquire heat enough to make the maſs take fire.

That heat and fire ſhould be generated from the ſpontaneous actions of *minerals* upon each other, is a phenomenon by no means ſingular in nature, how difficult ſoever it may be to account for it. The heat of putreſcent dunghills, of the fermenting juices of vegetables, and, above all, the ſpontaneous firing of hay not properly dried, are obvious proofs that *vegetables* poſſeſs this property as well as minerals. In both vegetables and minerals, a definite quantity of moiſture is requiſite to enable them to commence that inteſtine motion of their parts, which is neceſſary for the production of fire. Iron and ſulphur would remain mixed together for ages without taking fire, if they were either kept perfectly free from moiſture, or drenched with too much water; and vegetables in like manner, which are quite dry, or exceedingly wet, are incapable of taking fire whilſt they continue in that ſtate.

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culty which attends this explanation of the origin of volcanoes, as well as of earthquakes, is, that the presence of air is in general necessary for the production of actual flame. It is well known, however, that martial pyrites, when moistened, acquire heat; and if we suppose the heated pyrites to have been in contact with black wad and petroleum, we may suppose the flame to arise, as we see it produced by art, from the desiccation of the former substance, and its mixture with mineral oil. Many minerals, when heated, afford vital air, a very small quantity of which is sufficient to produce flame; this flame, once produced, may be supported from other ores, and the combustion be maintained by the presence of bituminous schistus, bitumen, and coal. Marl, schistus, horn-stone, shoerl, with a further addition of iron, are the true sources of lava. It seems, however, after all, difficult to conceive that such extensive and intense fires should be maintained without the access of considerable quantities of air; that substance may therefore be possibly supplied by a communication with some extensive caverns, which may themselves receive it by openings at the distance of many miles from the crater of the volcano. It does not seem improbable that the volcanoes, which now burn, may have a communication with the cavities and craters of extinguished volcanoes, and thence derive a supply of air sufficient to account for the inflammation of large beds of pyrites and bituminous matters. M. Buffon supposes, that the seat of volcanic fires is situated but a very little way below the bed of the mountains; but it appears

pears more probable, that it is in general many miles below the ſurface of the earth, for the quantity of matter diſcharged from Ætna alone is ſuppoſed, on a moderate calculation, to exceed twenty times the original bulk of the mountain, and therefore could not have been derived from it contents alone, but alſo from the deeper receſſes of the earth.

M. Condamine aſſerts, that all the mountains in the neighbourhood of Naples exhibit undoubted marks of a volcanic origin. He ſays, he could trace the lava, and other productions of ſubterraneous fire, from Naples to the very gates of Rome, pervading the whole ſoil, ſometimes pure and ſometimes differently combined. "Wherever I ſee," ſays he, "on an elevated plain, a circular baſon, ſurrounded with calcined rocks, I am not deceived by the verdure of the adjacent fields; I can diſcover, beneath the ſnow itſelf, the traces of an extinguiſhed fire. If there is a breach in the circle, I uſually find out, by following the declivity of the ground, the traces of a rivulet, or the bed of a torrent, which ſeems as if it was hollowed in the rock, and this rock appears frequently to be pure lava. If the circumference of the baſon has no breach, the rain and ſpring waters, which are collected there, generally form a lake in the very mouth of the volcano." The Apennines, as well as the Cordeliers of Peru and Chili, he ſuppoſes to have been a chain of volcanoes. The chain in both inſtances is interrupted, and many of the fires either extinguiſhed or ſmothered, but many remain ſtill actually burning. This intelligent author is, however, far from attributing

buting to all mountains the ſame origin; and adds, that in that part of the Alps, which he travelled over, he could obſerve no ſuch appearances.

The traces of volcanoes have been obſerved in Ireland by Mr. Whitehurſt. Though no viſible crater is remaining between Port Ruſh Strand and Balley Caſtle eaſtward, yet, he obſerves, that whole ſpace, about twenty Engliſh miles, is one continued maſs of lava. The cliffs, he ſays, are truly ſtupendous, and bear every poſſible mark of having been originally liquid fire. The elevation of that, at the foot of which the Giant's Cauſeway is ſituated, he preſumes cannot be leſs than five or ſix hundred feet perpendicular above the level of the Atlantic ocean, and yet compoſed entirely of lava; the ſame appearances extend towards the ſouth upwards of twenty miles.

The moſt remarkable volcanoes in Europe are Ætna and Veſuvius, and as theſe are not too far diſtant, we have the moſt accurate deſcriptions of them from travellers of the firſt talents and reputation.

'Ætna, which is the moſt ſtriking object in Sicily, and indeed one of the moſt magnificent productions of nature, ariſes from an immenſe baſe, and mounts equally on all ſides to its ſummit. The aſcent on each ſide is computed at about thirty miles, and the circumference of its baſe, at one hundred and thirty-three; but as it has never been meaſured with any great degree of accuracy, its dimenſions are but imperfectly known.

'The whole mountain is divided into three diſtinct regions, called *La Regione Culta*, or *Piedmonteſe*, the fertile regions; *La Regiona Sylvoſa*, or *Nemoroſa*, the woody region; and *La Regiona Deſerta*, or *Scoperta*, the barren region. Theſe differ as materially both in climate and production as the three zones of the earth, and perhaps with equal propriety might have been ſtiled the torrid, the temperate, and the frigid zone.

'The firſt region of Ætna ſurrounds the baſe of the mountain, and conſtitutes the moſt fertile country in the world on all ſides of it, to the extent of fourteen or fifteen miles, where the woody region begins. It is compoſed almoſt entirely of lava, which, in time, becomes the moſt fertile of all ſoils, but the roads, which are entirely over old lavas, now converted into orchards, vineyards, and corn-fields, are very execrable. The lavas, which form this region, ariſe from a number of beautiful little mountains, every where ſcattered over the immenſe declivities of Ætna. Theſe are all either of a conical or ſemi-ſpherical figure, and are in general covered with beautiful trees, and the moſt luxurious verdure. The formation of them is owing to the internal fires of Ætna, which raging for a vent, at ſo vaſt a diſtance from the great crater that it cannot poſſibly be carried to the height of twelve or thirteen thouſand feet, which is probably the height of the ſummit of Ætna, muſt neceſſarily be diſcharged at ſome other orifice. After ſhaking the mountain, and its neighbourhood for ſome time, at length the fire burſts open its ſide, and this is called an eruption. At firſt it emits only

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a thick ſmoke and ſhowers of aſhés. Theſe are followed by red hot ſtones, and rocks of a great ſize, which are thrown to an immenſe height in the air. Theſe ſtones, together with the quantities of aſhes diſcharged at the ſame time, form thoſe mountains, which cover all the declivities of Ætna. The ſize of them is in proportion to the duration of the eruption. When it continues a conſiderable time, it ſometimes forms an elevation of one thouſand feet in perpendicular height, which at its baſe is ſeven or eight miles in circumference.

'After the formation of the new mountain, the lava commonly burſts out from its lower ſide, and, ſweeping every thing before it, is generally terminated by the ſea. Sometimes it iſſues from the ſide of the mountain, without theſe attending circumſtances, which is commonly the caſe with the eruptions of Veſuvius, in which the elevation being ſo much ſmaller the melted matter is carried up into the crater, where it is diſlodged without forming any new mountain, but only adding to the height of the old one; till at length the lava, riſing near the ſummit, burſts the ſide of the crater. But Ætna being upon a much larger ſcale, one crater is not ſufficient to give vent to ſuch immenſe oceans of liquid fire.

'At Nicoloſi, which is only twelve miles up the mountain, the climate appears totally changed. When the heats at Catania are inſupportable, and the harveſt entirely over, the temperature of the air is moderate at Nicoloſi, and in many places the corn quite green. Mr. Brydone, in travelling over Ætna,

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was struck with the degree of wildness and ferocity which appeared in the inhabitants of the mountain, and which reminded him of an observation made by the Padre della Tore, the historiographer of Mount Vesuvius, that in places where the air is most impregnated with sulphur and hot exhalations, the people are always most wicked and vicious. It was with great difficulty he could persuade the people of Nicolosi to suffer his guide to attend him in the prosecution of his researches. They were excessively troublesome, and extremely suspicious that his views were directed to the discovery of some hidden treasure, the only motive to which they could ascribe so fatiguing a journey. At length one of them recollected having heard many of their old people say, that the English had a queen that had burnt in the mountain for many years past, and imputed the visits of several of that nation to their respect to their deceased sovereign. Upon enquiring who this queen was, they said her name was Anna, that she was wife to a king who had been a christian, but she had made him a heretic, and was condemned to burn for ever in Mount Ætna. As this could only relate to the unfortunate Anne Bullen, Mr. Brydone asked if she was the victim alluded to, and whether her husband was not likewise condemned to the same punishment. "Certainly," said the man, "and all his heretic subjects too; and if you are of that number you need not be in such a hurry to get there, you will be sure of it at last."

'The beautiful country of Hybla, in the neighbourhood of Nicolosi, after repeated vicissitudes, is

now reduced to a melancholy monument of the fury of Ætna; it was ſo much celebrated for its fertility, and particularly for its honey, that it was called Mel Paſſi, till it was overwhelmed by the lava of Ætna, and became totally barren, when, by a kind of pun, it obtained the name of Mal Paſſi. On a ſecond eruption, however, a fertile ſhower of aſhes reſtored its priſtine beauty, and its former appellation. But in the dreadful eruption of 1669 it was again reduced to the moſt deplorable ſterility, ſince which it is once more known by the name which denotes its wretchedneſs. The eruption that firſt deſtroyed this beautiful country, iſſued from Montpelieri, which it then formed. It deſtroyed a great number of villages and palaces, and in particular two noble churches, which are extremely regreted on account of three ſtatues, accounted, at that time, the moſt perfect in the iſland. They have attempted to recover them, but in vain, nor is it believed they ever can; for the churches were built of lava, which is ſuppoſed to melt as ſoon as it comes into contact with a torrent of new erupted matter. Maſſa, a Sicilian author of great credit, affirms, that in ſome eruptions of Ætna, the lava has poured down with ſuch a ſudden impetuoſity, that, in the courſe of a few hours, palaces, churches, and villages, have been entirely melted down, and the whole run off in fuſion. It is however probable, that the impetuous force of the torrent, rather than its incorporating with the old maſs, may in many of theſe inſtances have occaſioned this devaſtation. Thus much at leaſt is certain, that if

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the lava has had any confiderable time to cool, this fingular effect never happens.

The contraft between the different regions of Ætna is extremely ftriking. On entering into the romantic forefts of the Regione Sylvofa, a new creation feems to arife. The air, which before was hot and fultry, is cool and refrefhing, and every breeze loaded with delicious perfumes from the aromatic plants, with which the whole ground is covered. Indeed every beauty, and every horror in nature, feems to be united on this wonderful mountain, and the moft oppofite and diffimilar objects are promifcuoufly blended together. Here we obferve a gulph which threw out torrents of fire, now covered with the moft luxurious verdure. Delicious fruits arifing from what was but lately a black and barren rock. Delightful flowers covering the earth, the furface of which is but a few yards removed from lakes of liquid fire and brimftone. An immenfe gulph of fire for ever exifting in the midft of fnows which it has not the power to melt, and immenfe fields of fnow and ice unceafingly furrounding this gulph of fire which they have not the power to extinguifh.

The woody region of Ætna afcends for about eight or nine miles, and forms a zone of the brighteft green around the mountain. In this region, near the *Spelonca del Capriole*, or goats cavern, are two of the moft beautiful mountains that adorn the fides of Ætna. Their hollow craters are each of them confiderably larger than that of Vefuvius. They are now filled with ftately oaks, and covered with the richeft foil to a great depth. A mountain at fome diftance

which was formed by an eruption in 1766, was, in 1770, ſtill on fire; nor was the lava by any means cold. This region of Ætna, like the *Regione Culta*, is compoſed of lava; but this is now covered with ſo deep a layer of earth, that it is no where to be ſeen, except in the beds of the torrents, in many of which it is worn down by the water to the depth of fifty or ſixty feet, and in one of them conſiderably more. On approaching *La Regione Scoperta*, the trees begin to aſſume a wintry appearance, and every object indicates the proximity of barrenneſs and eternal froſt.

On completely bidding adieu to the vegetable regions, an expanſe of ice preſents itſelf, which is ſufficient to ſtagger the moſt determined reſolution. Above theſe the high ſummit of the mountain rears its tremendous head, vomiting torrents of thick ſmoke. The difficulty of aſcending this part of the mountain is greatly increaſed by the uncertainty of a ſecure footing; for the ſurface of the mountain being hot below, frequently melts the ſnow in particular ſpots, and forms pools of water where it is impoſſible to foreſee the danger; ſometimes, likewiſe, it happens that the ſurface of the water, as well as the ſnow, is covered with black aſhes, which render it exceedingly deceitful. At firſt the aſcent is not ſo ſteep, but it becomes ſo by degrees. In this region are the remains of an ancient ſtructure called *Il Torre del Filoſofo*, and ſuppoſed to have been built by Empedocles, a native of Agrigentum, who is ſaid to have died 400 years before the chriſtian era. His vanity, perhaps, rather than his philoſophy, led him

him to this elevated ſituation. Deſirous of being regarded as a god, he is recorded to have thrown himſelf into the great gulph of Ætna, in hopes that the people would imagine he had been taken up to heaven, and never ſuppoſing that his death would be diſcovered to mankind. But the treacherous mountain threw out his ſlippers, which were of braſs, and announced to the world the fate of the pretended philoſopher, who preferred an airy fame, which he was beyond the reach of enjoying, to the ſolid advantages of exiſtence, and who was content to purchaſe the admiration of an ignorant multitude with the meanneſs of deceit, and the ſacrifice of life. *

Many ſtriking remains of the great eruption in 1669 are ſtill to be ſeen, and will long continue as memorials of that dreadful event which overwhelmed Catania, and all the adjacent country. Tremendous earthquakes ſhook the iſland, and loud ſubterraneous bellowings were heard in the mountain. During ſome weeks, the ſun ceaſed to appear, and the day ſeemed changed into night. Borelli, who was a witneſs to theſe terrible phenomena, ſays, that at length a rent, twelve miles in length, was opened in the mountain, in ſome places of which, when they threw down ſtones, they could not hear them reach the bottom. Burning rocks, ſixty palms in length, were thrown to the diſtance of a mile, and leſſer ſtones were carried three miles. After the moſt violent ſtruggles, and a ſhaking of the whole iſland, an immenſe torrent of lava guſhed from the rent, and

* See preſent ſtate of Sicily and Malta.

ſprung up into the air to the heighth of ſixty palms, whence it poured down the mountain, overwhelming every object in its way in one promiſcuous ruin.

This deſtructive torrent, which burſt from the ſide of Ætna at a place called Ricini, ruſhed impetuouſly againſt the beautiful mountain of Montpelieri, and pierced into the ground to a conſiderable depth; then dividing and ſurrounding the mountain, it united again on the ſouth ſide, and poured deſolation upon the adjacent country. The progreſs of the torrent was at firſt at the rate of ſeven miles a day, but it afterwards took four days to travel ſixteen; wherever it directed its courſe, the whole appearance of nature was changed, ſeveral hills were formed in places which were formerly valleys, and a large lake was ſo entirely filled up by the melted maſs, as not to leave a veſtige remaining. In its courſe it deſcended upon a vineyard, belonging to a convent of Jeſuits, which was formed upon an ancient and probably a very thin layer of lava, with a number of caverns and crevices under it. The liquid maſs entering into theſe excavations ſoon filled them up, and by degrees bore up the vineyard, which in a ſhort time, to the great aſtoniſhment of the ſpectators, began to move away, and was carried by the torrent to a conſiderable diſtance. In 1770 ſome remains of this vineyard were ſtill to be ſeen, but the greater part of it was entirely deſtroyed.

In vain did the terrified inhabitants of Catania recur for protection to the miraculous veil, or expect defence from the lofty walls of their city. After deſtroying

destroying several convents, churches, and villages, this fiery current directed its course to Catania, where it poured impetuously over the ramparts, which are near sixty feet in height, and covered up five of its bastions, with the intervening curtains. After laying waste a great part of this beautiful city, and entirely destroying several valuable remains of antiquity, its further progress was stopped by the ocean, over whose banks it poured its destructive current. In its course from the rent in the mountain, till its arrival in the sea, it is said to have totally destroyed the property of near thirty thousand persons.

Still however did the infatuated inhabitants of Catania adhere to the remains of their almost ruined city, nor did even the more dreadful calamity with which they were afterwards visited, abate their attachment. Twenty-four years after the fatal eruption of 1669, a violent earthquake, which extended along all the eastern coast, and destroyed in one hour more than sixty thousand persons, overthrew the remaining buildings of Catania, and buried a very considerable number of its inhabitants under the ruins of their houses and churches; but again the place was rebuilt, a new and elegant plan was adopted, and the city is now much handsomer than before. The principal streets are wide, strait, and well paved with lava. The cathedral, which was founded in the year 1094, has suffered so greatly from earthquakes that a very small part of the original structure remains. The other religious edifices are profusely ornamented, but in a bad taste.

But if the united effects of attachment to their native soil, of contempt for dangers to which they are habituated, and of confidence in the miraculous veil, have occasioned the wonderful adherence of the Catanians to this dangerous situation from which they have so severely suffered, it must, however, be confessed that they have sometimes derived advantages from the very evils which they have so much reason to dread. They were always in great want of a port, with which they were furnished by one of those capricious changes which nature so frequently makes in this ever varying spot. A stream of lava running into the sea, formed a mole, which no expence could have furnished them with. This advantage, however, proved but temporary; there remained for some time a safe and commodious harbour, but by a subsequent eruption it was entirely filled up and demolished.

The celebrated Bishop Berkeley has described an eruption of Mount Vesuvius, of which he was a witness in the year 1717, and the reader will find his narrative in the first volume of Dr. Goldsmith's History of the Earth and Animated Nature, p. 94. But the most complete and philosophical account of this most formidable phenomenon, a volcanic explosion, is that with which Sir William Hamilton has favoured the public, in describing the late dreadful eruption of that mountain in 1794; and this I shall endeavour to give, as nearly as possible, in his own words.

Sir William begins his narrative with remarking, that the frequent slight eruptions of lava for some years past had issued from near the summit, and ran

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in ſmall channels in different directions down the flanks of the mountain, and from running in covered channels, had often an appearance as if they came immediately out of the ſides of Veſuvius, but ſuch lavas had not ſufficient force to reach the cultivated parts at the foot of the mountain. In the year 1779, the whole quantity of the lava in fuſion having been at once thrown up with violence out of the crater of Veſuvius, and a great part of it falling, and cooling on its cone, added much to the ſolidity of the walls of this huge natural chimney, and had not of late years allowed of a ſufficient diſcharge of lava to calm that fermentation, which by the ſubterraneous noiſes heard at times, and by the exploſions of ſcoriæ and aſhes, was known to exiſt within the bowels of the volcano; ſo that the eruptions of late years, before this laſt, were ſimply from the lava having boiled over the crater, the ſides being ſufficiently ſtrong to confine it, and oblige it to riſe and overflow. The mountain had been remarkably quiet for ſeven months before the late eruption, nor did the uſual ſmoke iſſue from its crater, but at times it emitted ſmall clouds of ſmoke that floated in the air in the ſhape of little trees. It was remarked by the Father Antonio di Petrizzi, a capuchin friar (who printed an account of the late eruption) from his convent cloſe to the unfortunate town of Torre del Greco, that for ſome days preceding this eruption a thick vapour was ſeen to ſurround the mountain, about a quarter of a mile beneath its crater, as it was remarked by him, and others at the ſame

time, that both the ſun and the moon had often an unuſual reddiſh caſt.

The water of the great fountain at Torre del Greco began to decreaſe ſome days before the eruption, ſo that the wheels of a corn-mill, worked by that water, moved very ſlowly; it was neceſſary in all the other wells of the town and its neighbourhood to lengthen the ropes daily, in order to reach at the water; and ſome of the wells became quite dry. Although moſt of the inhabitants were ſenſible of this phenomenon, not one of them ſeems to have ſuſpected the true cauſe of it. Eight days alſo before the eruption, a man and two boys, being in a vineyard above Torre del Greco (and preciſely on the ſpot where one of the new mouths opened, whence the principal current of lava that deſtroyed the town iſſued) were much alarmed by a ſudden puff of ſmoke which iſſued from the earth cloſe to them, and was attended with a ſlight exploſion.

Had this circumſtance, with that of the ſubterraneous noiſes heard at Reſina for two days before the eruption (with the additional one of the decreaſe of water in the wells) been communicated at the time, it would have required no great foreſight to have been certain that an eruption of the volcano was near at hand, and that its force was directed particularly towards that part of the mountain.

On the 12th of June 1794, in the morning, there was a violent fall of rain, and ſoon after the inhabitants of Reſina, ſituate directly over the ancient town of Herculaneum, were ſenſible of a rumbling

rumbling ſubterraneous noiſe, which was not heard at Naples.

From the month of January to the month of May, the atmoſphere was generally calm, and there was continued dry weather. In the month of May there was a little rain, but the weather was unuſually ſultry. For ſome days preceding the eruption, the Duke della Torre, a learned and ingenious nobleman, who publiſhed two letters upon the ſubject of the eruption, obſerved by his electrometers, that the atmoſphere was charged in exceſs with the electric fluid, and continued ſo for ſeveral days during the eruption.

About eleven o'clock on the night of the 12th of June, the inhabitants of Naples were all ſenſible of a violent ſhock of an earthquake; the undulatory motion was evidently from eaſt to weſt, and appeared to have laſted near half a minute. The ſky, which had been quite clear, was ſoon after covered with black clouds. The inhabitants of the towns and villages, which are very numerous at the foot of Veſuvius, felt this earthquake ſtill more ſenſibly, and ſay, that the ſhock at firſt was from the bottom upwards, after which followed the undulation from eaſt to weſt. This earthquake extended all over the Campagna Felice; and the royal palace at Caſerta, which is fifteen miles from Naples, and one of the moſt magnificent and ſolid buildings in Europe (the walls being eighteen feet thick) was ſhook in ſuch a manner as to cauſe great alarm, and all the chamber bells rang. It was likewiſe

likewise much felt at Beneventum, about thirty miles from Naples; and at Ariano in Puglia, which is at a much greater distance; both these towns, indeed, have been often afflicted with earthquakes.

On Sunday the 15th of June, soon after ten o'clock at night, another shock of an earthquake was felt at Naples, but did not appear to be quite so violent as that of the 12th, nor did it last so long; at the same moment a fountain of bright fire, attended with a very black smoke and a loud report, was seen to issue, and rise to a great height, from about the middle of the cone of Vesuvius; soon after another of the same kind broke out at some little distance lower down; then, as is supposed by the blowing up of a covered channel full of red hot lava, it had the appearance as if the lava had taken its course directly up the steep cone of the volcano. Fresh fountains succeeded one another hastily, and all in a direct line tending, for about a mile and a half down, towards the towns of Resina and Torre del Greco. Sir William Hamilton could count fifteen of them, but believes there were others obscured by the smoke. It seems probable, that all these fountains of fire, from their being in such an exact line, proceeded from one and the same long fissure down the flanks of the mountain, and that the lava and other volcanic matter forced its way out of the widest parts of the crack, and formed there the little mountains and craters that will be described in their proper place. It is impossible that any description can give an idea of this fiery scene,

ſcene, or of the horrid noiſes that attended this great operation of nature. It was a mixture of the loudeſt thunder, with inceſſant reports, like thoſe from a numerous heavy artillery, accompanied by a continued hollow murmur, like that of the roaring of the ocean during a violent ſtorm; and, added to theſe was another blowing noiſe, like that of the aſcending of a large flight of ſky-rockets, or that which is produced by the action of the enormous bellows on the furnace of the Carron iron foundery in Scotland. The frequent falling of the huge ſtones and ſcoriæ, which were thrown up to an incredible height from ſome of the new mouths, and one of which having been ſince meaſured by the Abbé Tata was ten feet high, and thirty-five in circumference, contributed undoubtedly to the concuſſion of the earth and air, which kept all the houſes at Naples for ſeveral hours in a conſtant tremor, every door and window ſhaking and rattling inceſſantly, and the bells ringing. This was an awful moment! The ſky, from a bright full moon and ſtar-light, began to be obſcured; the moon had preſently the appearance of being in an eclipſe, and ſoon after was totally loſt in obſcurity. The murmur of the prayers and lamentations of a numerous populace forming various proceſſions, and parading in the ſtreets, added to the horror. As the lava did not appear to have yet a ſufficient vent, and it was now evident that the earthquakes already felt had been occaſioned by the air and fiery matter confined within the bowels of the mountain, and probably

probably at no ſmall depth (conſidering the extent of thoſe earthquakes) Sir William recommended to the company that was with him, who began to be much alarmed, rather to go and view the mountain at ſome greater diſtance, and in the open air, than to remain in the houſe, which was on the ſea-ſide, and in the part of Naples that is neareſt and moſt expoſed to Veſuvius. They accordingly proceeded to Poſilipo, and viewed the conflagration, now become ſtill more conſiderable, from the ſea-ſide under that mountain; but whether from the eruption having increaſed, or from the loud reports of the volcanic exploſions being repeated by the mountain behind them, the noiſe was much louder, and more alarming than that they had heard in their firſt poſition, at leaſt a mile nearer to Veſuvius. After ſome time, and which was about two o'clock in the morning of the 16th, having obſerved that the lavas ran in abundance, freely, and with great velocity, having made a conſiderable progreſs towards Reſina, the town which it firſt threatened, and that the fiery vapours which had been confined had now free vent through many parts of a crack of more than a mile and a half in length, as was evident from the quantity of inflamed matter and black ſmoke, which continued to iſſue from the new mouths above mentioned, without any interruption, our author concluded that at Naples all danger from earthquakes, which had been his greateſt apprehenſion, was totally removed, and he returned to his former ſtation at St. Lucia at Naples.

All this time there was not the ſmalleſt appearance of fire or ſmoke from the crater on the ſummit of Veſuvius; but the black ſmoke and aſhes iſſuing continually from ſo many new mouths, or craters, formed an enormous and denſe body of clouds over the whole mountain, and which began to give ſigns of being replete with the electric fluid, by exhibiting flaſhes of that ſort of zig-zag lightning, which in the volcanic language of the country is called *ferilli*, and which is the conſtant attendant on the moſt violent eruptions.

Sir William Hamilton proceeds to remark, that during thirty years that he had reſided at Naples, and in which ſpace of time he had been witneſs ■ many eruptions of Veſuvius, of one ſort or other, he never ſaw the cloud of ſmoke replete with the electric fire, except in the two great eruptions of 1767, that of 1779, and during this more formidable one. The electric fire, in the year 1779, that played conſtantly within the enormous black cloud over the crater of Veſuvius, and ſeldom quitted it, was exactly ſimilar to that which is produced, on a very ſmall ſcale, by the conductor of an electrical machine communicating with an inſulated plate of glaſs, thinly ſpread over with metallic filings, &c. when the electric matter continues to play over it in zig-zag lines without quitting it. He was not ſenſible of any noiſe attending that operation in 1779; whereas the diſcharge of the electrical matter from the volcanic clouds during this eruption, and particularly the ſecond and third days, cauſed exploſions like thoſe of the loudeſt thunder;

thunder; and indeed the ſtorms raiſed evidently by the ſole power of the volcano, reſembled in every reſpect all other thunder-ſtorms; the lightning falling and deſtroying every thing in its courſe. The houſe of the Marquis of Berio at St. Jorio, ſituate at the foot of Veſuvius, during one of theſe volcanic ſtorms was ſtruck with lightning, which having ſhattered many doors and windows, and damaged the furniture, left for ſome time a ſtrong ſmell of ſulphur in the rooms it paſſed through. Out of theſe gigantic and volcanic clouds, beſides the lightning, both during this eruption and that of 1779, the author adds, he had, with many others, ſeen balls of fire iſſue, and ſome of a conſiderable magnitude, which burſting in the air, produced nearly the ſame effect as that from the air-balloons in fire-works, the electric fire that came out having the appearance of the ſerpents with which thoſe fire-work balloons are often filled. The day on which Naples was in the greateſt danger from the volcanic clouds, two ſmall balls of fire, joined together by a ſmall link like a chain-ſhot, fell cloſe to his Caſino at Poſilipo; they ſeparated, and one fell in the vineyard above the houſe, and the other in the ſea, ſo cloſe to it that he heard the ſplaſh in the water. The Abbé Tata, in his printed account of this eruption, mentions an enormous ball of this kind which flew out of the crater of Veſuvius while he was ſtanding on the edge of it, and which burſt in the air at ſome diſtance from the mountain, ſoon after which he heard a noiſe like

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the fall of a number of ſtones, or of a heavy ſhower of hail. During the eruption of the 15th at night, few of the Inhabitants of Naples, from the dread of earthquakes, ventured to go to their beds. The common people were either employed in devout proceſſions in the ſtreets, or were ſleeping on the quays and open places; the nobility and gentry, having cauſed their horſes to be taken from their carriages, ſlept in them in the ſquares and open places, or on the high roads juſt out of the town. For ſeveral days, while the volcanic ſtorms of thunder and lightning laſted, the inhabitants at the foot of the volcano, both on the ſea ſide and the Somma ſide, were often ſenſible of a tremor in the earth, as well as of the concuſſions in the air, but at Naples only the earthquakes of the 12th and 15th of June were diſtinctly and univerſally felt: this fair city could not certainly have reſiſted, had not thoſe earthquakes been fortunately of a ſhort duration. Throughout this eruption, which continued in force about ten days, the fever of the mountain, as has been remarked in former eruptions, ſhowed itſelf to be in ſome meaſure periodical, and generally was moſt violent at the break of day, at noon, and at midnight.

About four o'clock in the morning of the 16th, the crater of Veſuvius began to ſhow ſigns of being open, by ſome black ſmoke iſſuing out of it; and at day-break another ſmoke, tinged with red, iſſuing from an opening near the crater, but on the other ſide of the mountain, and facing the town of Ottai-

ano,

ano, ſhewed that a new mouth had opened there from which a conſiderable ſtream of lava iſſued, and ran with great velocity through a wood, which it burnt; and having run about three miles in a few hours it ſtopped before it had arrived at the vineyards and cultivated lands. The crater, and all the conical part of Veſuvius, was ſoon involved in clouds and darkneſs, and ſo it remained for ſeveral days; but above theſe clouds, although of a great height, freſh columns of ſmoke were ſeen from the crater, riſing furiouſly ſtill higher, until the whole maſs remained in the uſual form of a pine-tree; and in that gigantic maſs of heavy clouds the ferilli, or volcanic lightning, was frequently viſible, even in the day time. About five o'clock in the morning of the 16th, the lava which had firſt broken out from the ſeveral new mouths on the ſouth ſide of the mountain, had reached the ſea, and was running into it, having overwhelmed, burnt, and deſtroyed the greateſt part of Torre del Greco, the principal ſtream of lava having taken its courſe through the very center of the town (ſee plate II.) *. They obſerved from Naples, that when the lava was in the vineyards in its way to the town, there iſſued often, and in different parts of it, a bright pale flame, and very different from the deep red of the lava; this was occaſioned by the burning of the trees that

* This view was taken from a boat on the ſea near that town, about five in the morning of the 16th of June, and while the lava was ſtill advancing in the ſea. The rocks, on which are two figures near the boat, were formed by a lava that ran into the ſea during a former eruption of Mount Veſuvius.

ſupported

Vol. II. p. 384. Plate

supported the vines. Soon after the beginning of this eruption, ashes fell thick at the foot of the mountain, all the way from Portici to the Torre del Greco; and what is remarkable, although there were not at that time any clouds in the air, except those of smoke from the mountain, the ashes were wet, and accompanied with large drops of water, which were to the taste very salt; the road, which is paved, was as wet as if there had been a heavy shower of rain. Those ashes were black and coarse, like the sand of the sea-shore, whereas those that fell there, and at Naples some days after, were of a light-grey colour, and as fine as Spanish snuff, or powdered bark. They contained many saline particles; those ashes that lay on the ground, exposed to the burning sun, had a coat of the whitest powder on their surface, which to the taste was extremely salt and pungent. In the printed account of the eruption by Emanuel Scotti, doctor of physic and professor of philosophy in the university of Naples, he supposes (which appears to be highly probable) that the water which accompanied the fall of the ashes at the beginning of the eruption, was produced by the mixture of the inflammable and dephlogisticated air.

By the time that the lava had reached the sea, between five and six o'clock in the morning of the 16th, Vesuvius was so completely involved in darkness, that the violent operation of nature that was going on there could no longer be discerned, and so it remained for several days; but the dreadful noise, and the red tinge on the clouds over the

top of the mountain, were evident ſigns of the activity of the fire underneath. The lava ran but ſlowly at Torre del Greco after it had reached the ſea; and on the 17th of June in the morning, its courſe was ſtopped, excepting that at times a little rivulet of liquid fire iſſued from under the ſmoaking ſcoriæ into the ſea, and cauſed a hiſſing noiſe, and a white vapour ſmoke; at other times, a quantity of large ſcoriæ were puſhed off the ſurface of the body of the lava into the ſea, diſcovering that it was redhot under that ſurface; and even to the latter end of Auguſt the center of the thickeſt part of the lava that covered the town retained its red heat. The breadth of the lava that ran into the ſea, and formed a new promontory there, after having deſtroyed the greateſt part of the town of Torre del Greco, having been exactly meaſured by the duke della Torre, is of Engliſh feet 1204. Its height above the ſea is twelve feet, and as many feet under water; ſo that its whole height is twenty-four feet; it extends into the ſea 626 feet. The ſea water was boiling as in a cauldron, where it waſhed the foot of this new formed promontory: and although our author was at leaſt a hundred yards from it, obſerving that the ſea ſmoked near his boat, he put his hand into the water, which was literally ſcalded; and by this time his boatmen obſerved that the pitch from the bottom of the boat was melting faſt, and floating on the ſurface of the ſea, and that the boat began to leak; he therefore retired haſtily from this ſpot, and landed at ſome diſtance from the hot lava. The

town

town of Torre del Greco contained about 18,000 inhabitants, all of whom (except about 15, who from either age or infirmity could not be moved, and were overwhelmed by the lava in their houses) escaped either to Castel-a-mare, which was the ancient Stabiæ, or to Naples; but the rapid progress of the lava was such, after it had altered its course from Resina, which town it first threatened, and had joined a fresh lava that issued from one of the new mouths in a vineyard, about a mile from the town, that it ran like a torrent over the town of Torre del Greco, allowing the unfortunate inhabitants scarcely time to save their lives; their goods and effects were totally abandoned, and indeed several of the inhabitants, whose houses had been surrounded with lava while they remained in them, escaped from them, and saved their lives the following day, by coming out of the tops of their houses, and walking over the scoriæ on the surface of the redhot lava. Five or six old nuns were taken out of a convent in this manner, on the 16th of June, and carried over the hot lava; their stupidity was such, as not to have been the least alarmed, or sensible of their danger: one of upwards of ninety years of age was found actually warming herself at a point of redhot lava, which touched the window of her cell, and which she said was very comfortable; and though now apprized of their danger, they were still very unwilling to leave the convent, in which they had been shut up almost from their infancy, their ideas being as limited as the space they inhabited. Having been desired to pack up whatever

they had that was moſt valuable, they all loaded themſelves with biſcuits and ſweetmeats, and it was but by accident it was diſcovered that they had left a ſum of money behind them, which was recovered for them.

The lava paſſed over the center and beſt part of the town; no part of the cathedral remained above it, except the upper part of a ſquare brick tower, in which were the bells; and it is a curious circumſtance, that thoſe bells, although they were neither cracked nor melted, were deprived of their tone as much as if they had been cracked. When the lava firſt entered the ſea, it threw up the water to a prodigious height; and particularly when two points of lava met and incloſed a pool of water, that water was thrown up with great violence, and a loud report: at this time, as well as the day after alſo, a great many boiled fiſh were ſeen floating on the ſurface of the ſea.

The lava over the cathedral, and in other parts of the town, is ſaid to be upwards of forty feet in thickneſs; the general height of the lava during its whole courſe was about twelve feet, and in ſome parts not leſs than a mile in breadth.

When Sir William Hamilton viſited it on the 17th of June, the tops of the houſes were juſt viſible here and there in ſome parts, and the timbers within ſtill burning cauſed a bright flame to iſſue out of the ſurface; in other parts, the ſulphur and ſalts exhaled in a white ſmoke from the lava, forming a white or yellow cruſt on the ſcoriæ round the ſpots where it iſſued with the greateſt force. He often

heard little explosions, and saw that they blew up, like little mines, fragments of the scoriæ and ashes into the air; these he supposes to have been occasioned either by rarefied air in confined cellars, or, perhaps, by small portions of gunpowder taking fire, as few in that country are without a gun and some little portion of gunpowder in their houses. As the church feasts there are usually attended with fireworks and crackers, a firework-maker of the town had a very great quantity of fireworks ready made for an approaching feast, and some gunpowder, all of which had been shut up in his house by the lava, a part of which had even entered one of the rooms; yet he actually saved all his fireworks and gunpowder some days after, by carrying them safely over the scoriæ of the lava, that was redhot underneath. The heat in the streets of the town, at this time, was so great as to raise the thermometer to very near one hundred degrees, and close to the hot lava it rose much higher. Sir William remarked in his way home, that there was a much greater quantity of the petroleum floating on the surface of the sea, and diffusing a very strong and offensive smell, than was usual; for at all times in calms, patches of this bituminous oil are to be seen floating on the surface of the sea between Portici and Naples, and particularly opposite a village called Pietra Bianca. The minute ashes continued falling at Naples; and the mountain, totally obscured by them, continued to alarm the inhabitants with repeated loud explosions.

On Wednesday June 18, the wind having for a short space of time cleared away the thick cloud from the top of Vesuvius, it was now discovered that a great part of its crater, particularly on the west side opposite Naples, had fallen in, which it probably did about four o'clock in the morning of that day, as a violent shock of an earthquake was felt at that moment at Resina, and other parts situate at the foot of the volcano. The clouds of smoke, mixed with the ashes, were of such a density as to appear to have the greatest difficulty in forcing their passage out of the now widely extended mouth of Vesuvius, which certainly, since the top fell in, cannot be much short of two miles in circumference. One cloud heaped on another, and succeeding one another incessantly, formed in a few hours such a gigantic and elevated column of the darkest hue over the mountain, as seemed to threaten Naples with immediate destruction, having at one time been bent over the city, and appearing to be much too massive and ponderous to remain long suspended in the air; it was, besides, replete with the ferilli, or volcanic lightning, which was stronger than common lightning, just as Pliny the younger describes it in one of his letters to Tacitus, when he says *fulgoribus illæ et similes et majores erant**. (See plate III.) Vesuvius

* This view was taken from Naples, and gives a very good idea of the appearance of Mount Vesuvius, like a molehill, in comparison of the enormous mass that hung over it.—The black lines show the form of the top of Vesuvius, as it was before this eruption, and when the crater was only the width of the upper line,

Veſuvius was at this time completely covered, as were all the old black lavas, with a thick coat of thoſe fine light-grey aſhes already fallen, which gave it a cold and horrid appearance; and in compariſon of the abovementioned enormous maſs of clouds, which certainly, however it may contradict our idea of the extenſion of our atmoſphere, roſe many miles above the mountain, it appeared like a molehill, although the perpendicular height of Veſuvius, from the level of the ſea, is more than three thouſand ſix hundred feet. The abbé Braccini, as appears in his printed account of the eruption of Mount Veſuvius in 1631, meaſured with a quadrant the elevation of a maſs of clouds of the ſame nature, that was formed over Veſuvius during that great eruption, and found it to exceed thirty miles in height. Dr. Scotti, in his printed account of this eruption, ſays, that the height of this threatning cloud of ſmoke and aſhes, meaſured from Naples, was found to be of an elevation of thirty degrees.

The ſtorms of thunder and lightning, attended at times with heavy falls of rain and aſhes, cauſing the moſt deſtructive torrents of water and glutinous mud, mixed with huge ſtones, and trees torn up by the roots, continued more or leſs to afflict the inhabitants on both ſides of the volcano until the 7th of July, when the laſt torrent deſtroyed many hundred acres of cultivated land, between the towns

line. On the ſide of the mountain is repreſented the ſpot whence the lava firſt iſſued on the 15th of June, with its courſe to Torre del Greco and the ſea.

of Torre del Greco and Torre dell' Annunziata. Some of these torrents, both on the sea side and the Somma side of the mountain, came down with a horrid rushing noise; and some of them, after having forced their way through the narrow gullies of the mountain, rose to the height of more than twenty feet, and were near half a mile in extent. The mud, of which the torrents were composed, being a kind of natural mortar, completely cased up and ruined some thousand acres of rich vineyards; for it soon becomes so hard, that nothing less than a pickaxe can break it up.

The laudable curiosity of our author induced him to go upon Mount Vesuvius, as soon as it was consistent with any degree of prudence, which was not until the 30th of June, and even then it was attended with some risk. The crater of Vesuvius, except at short intervals, had been continually obscured by the volcanic clouds from the 16th, and was so on that day, with frequent flashes of lightning playing in those clouds, and attended as usual with a noise like thunder; and the fine ashes were still falling on Vesuvius, but still more on the mountain of Somma. Sir William went up the usual way by Resina, and observed, in his way through that village, that many of the stones of the pavement had been loosened, and were deranged by the earthquakes, particularly by that of the 18th, which attended the falling in of the crater of the volcano, and which had been so violent as to throw many people down, and obliged all the inhabitants of Resina to quit their houses hastily, to which they did

did not dare return for two days. The leaves of all the vines were burnt by the aſhes that had fallen on them, and many of the vines themſelves were buried under the aſhes, and great branches of the trees that ſupported them had been torn off by their weight. In ſhort, nothing but ruin and deſolation was to be ſeen. The aſhes at the foot of the mountain were about ten or twelve inches thick on the ſurface of the earth, but in proportion as he aſcended, their thickneſs increaſed to ſeveral feet, not leſs than nine or ten in ſome parts; ſo that the ſurface of the old rugged lavas, that before was almoſt impracticable, was now become a perfect plain, over which he walked with the greateſt eaſe. The aſhes were of a light-grey colour, and exceedingly fine, ſo that by the footſteps being marked on them as on ſnow, he learnt that three ſmall parties had been up before him. He ſaw likewiſe the track of a fox, which appeared to have been quite bewildered, to judge from the many turns he had made. Even the traces of lizards and other little animals, and of inſects, were viſible on theſe fine aſhes. Sir William and his companion aſcended to the ſpot whence the lava of the 15th firſt iſſued, and followed the courſe of it, which was ſtill very hot (although covered with ſuch a thick coat of aſhes) quite down to the ſea at Torre del Greco, which is more than five miles. It was not poſſible to get up to the great crater of Veſuvius, nor had any one yet attempted it. The horrid chaſms that exiſted from the ſpot where the late eruption firſt took place, in a ſtrait line for near two

two miles toward the ſea, cannot be imagined. They formed vallies more than two hundred feet deep, and from half a mile to a mile wide; and where the fountains of fiery matter exiſted during the eruption, were little mountains with deep craters. Ten thouſand men, in as many years, could not make ſuch an alteration on the face of Veſuvius. Except the exhalations of ſulphureous and vitriolic vapours, which broke out from different ſpots of the line abovementioned, and tinged the ſurface of the aſhes and ſcoriæ in thoſe parts with either a deep or pale-yellow, with a reddiſh ochre colour, or a bright white, and in ſome parts with a deep green and azure blue (ſo that the whole together had the effect of an iris) all had the appearance of a ſandy deſart. Our adventurers then went on the top of ſeven of the moſt conſiderable of the new-formed mountains, and looked into their craters, which on ſome of them appeared to be little ſhort of half a mile in circumference; and although the exterior perpendicular height of any of them did not exceed two hundred feet, the depth of their inverted cone within was three times as great. It would not have been poſſible to have breathed on theſe new mountains near their craters, if they had not taken the precaution of tying a doubled handkerchief over their mouths and noſtrils; and even with that precaution they could not reſiſt long, the fumes of the vitriolic acid were ſo exceedingly penetrating, and of ſuch a ſuffocating quality. They found in one a double crater, like two funnels joined together; and in all there

there was ſome little ſmoke and depoſitions of ſalts and ſulphurs, of the various colours abovementioned, juſt as is commonly ſeen adhering to the inner walls of the principal crater of Veſuvius.

Two or three days after they had been there, one of the new mouths, into which they had looked, ſuddenly made a great exploſion of ſtones, ſmoke, and aſhes, which would certainly have proved fatal to any one who might unfortunately have been there at the time of the exploſion. We read of a like accident having proved fatal to more than twenty people, who had the curioſity to look into the crater of the Monte Nuovo, near Pozzuoli, a few days after its formation, in the year 1538. The 15th of Auguſt, Sir William ſaw a ſudden exploſion of ſmoke and aſhes thrown to an extreme height out of the great crater of Veſuvius, that muſt have deſtroyed any one within half a mile of it; and yet on the 19th of July a party not only had viſited that crater, but had deſcended 170 feet within it. While they were on the mountain, two whirlwinds, exactly like thoſe that form water-ſpouts at ſea, made their appearance; and one of them, which was very near, made a ſtrange ruſhing noiſe, and having taken up a great quantity of the fine aſhes, formed them into an elevated ſpiral column, which, with a whirling motion and great rapidity, was carried toward the mountain of Somma, where it broke and was diſperſed. One of our author's ſervants, employed in collecting of ſulphur, or ſal ammoniac, which cryſtallizes near the fumaroli, as they are called (and which are the ſpots whence the hot

hot vapour iſſues out of the freſh lavas) found, to his great ſurprize, an exceeding cold wind iſſue from a fiſſure very near the hot fumaroli upon his leg. In a vineyard not in the ſame line with the new-formed mountains juſt deſcribed, but in a right line from them, at the diſtance of little more than a mile from Torre del Greco, they found three or four more of theſe new-formed mountains with craters, out of which the lava flowed, and by uniting with the ſtreams that came from the higher mouths, and adding to their heat and fluidity, enabled the whole current to make ſo rapid a progreſs over the unfortunate town, as ſcarcely to allow its inhabitants ſufficient time to eſcape with their lives. The rich vineyards belonging to the Torre del Greco, and which produced the wine called Lacrima Chriſti, that have been buried, and are totally deſtroyed by this lava, conſiſted of more than three thouſand acres; but the deſtruction of the vineyards by the torrents of mud and water, at the foot of the mountain of Somma, was much more extenſive.

In that part of the country, the firſt ſigns of a torrent that our author met with, was near the village of the Madonna dell' Arco, and he paſſed ſeveral others between that and the town of Ottaiano; one near Trochia, and two near the town of Somma, were the moſt conſiderable, and not leſs than a quarter of a mile in breadth; and, according to the teſtimony of eye-witneſſes, when they poured down from the mountain of Somma, they were from twenty to thirty feet high; the matter of theſe torrents was a liquid glutinous mud, compoſed of

ſcoriæ,

ſcoriæ, aſhes, ſtones (ſome of an enormous ſize) mixed with trees that had been torn up by the roots. Such torrents, as it may well be imagined, were irreſiſtible, and carried all before them; houſes, walls, trees, and not leſs than four thouſand ſheep and other cattle. At Somma, a team of eight oxen, which were drawing a large timber tree, were at once carried off, and never were heard of more.

The appearance of theſe torrents was like that of all other torrents in mountainous countries, except that what had been mud was become a perfect cement, on which nothing leſs than a pickaxe could make any impreſſion. The vineyards and cultivated lands were here much more ruined; and the limbs of the trees much more torn by the weight of the aſhes, than thoſe which have been already deſcribed on the ſea ſide of the volcano.

The abbé Tata, in his printed account of this eruption, has given a good idea of the abundance, the great weight, and glutinous quality of theſe aſhes, when he ſays, that having taken a branch from a fig-tree ſtill ſtanding near the town of Somma, on which were only ſix leaves, and two little unripe figs, and having weighed it with the aſhes attached to it, he found it to be thirty-one ounces; when having waſhed off the volcanic matter, it ſcarcely weighed three.

In the town of Somma, our author found four churches and about ſeventy houſes without roofs, and full of aſhes. The great damage on that ſide of the mountain, by the fall of the aſhes and the torrents, happened on the 18th, 19th, and 20th of June,

June, and on the 12th of July. The 19th, the ashes fell so thick at Somma, that unless a person kept in motion, he was soon fixed to the ground by them. This fall of ashes was accompanied also with loud reports, and frequent flashes of the volcanic lightning, so that, surrounded by so many horrors, it was impossible for the inhabitants to remain in the town, and they all fled; the darkness was such, although it was mid-day, that even with the help of torches it was scarcely possible to keep in the high road. On the 16th of July, signor Guiseppe Sacco went up to the crater, and, according to his account, which has been printed at Naples, the crater is of an irregular oval form, and, as he supposes (not having been able to measure it) of about a mile and a half in circumference; the inside, as usual, in the shape of an inverted cone, the inner walls of which on the eastern side are perpendicular; but on the western side of the crater, which is much lower, the descent was practicable, and Sacco with some of his companions actually went down one hundred and seventy-six palms, from which spot, having lowered a cord with a stone tied to it, they found the whole depth of the crater to be about five hundred palms. But such observations on the crater of Vesuvius are of little consequence, as both its form and apparent depth are subject to great alterations from day to day.

The 22d of July, one of the new craters, which is the nearest to the town of Torre del Greco, threw up both fire and smoke, which circumstance, added to that of the lava's retaining its heat much

longer

longer than uſual, ſeemed to indicate that there was ſtill ſome fermentation under that part of the volcano. The lava in cooling often cracks, and cauſes a loud exploſion, juſt as the ice does in the glaciers in Swiſſerland; ſuch reports were frequently heard at this time at the Torre del Greco; and a vapour was often ſeen to iſſue from the body of the lava, and taking fire in air, fall like thoſe meteors vulgarly called falling ſtars.

The darkneſs occaſioned by the fall of the aſhes in the Campagna Felice extended itſelf, and varied, according to the prevailing winds. On the 19th of June it was ſo dark at Caſerta, which is fifteen miles from Naples, as to oblige the inhabitants to light candles at mid-day; and one day, during the eruption, the darkneſs ſpread over Beneventum, which is thirty miles from Veſuvius.

The archbiſhop of Taranto, in a letter to Naples, and dated from that city the 18th of June, obſerves, 'We are involved in a thick cloud of minute volcanic aſhes, and we imagine that there muſt be a great eruption either of Mount Etna, or of Stromboli.' The biſhop did not dream of their having proceeded from Veſuvius, which is about two hundred and fifty miles from Taranto. Aſhes alſo fell, during the late eruption, at the very extremity of the province of Lecce, which is ſtill farther off; at Martino, near Taranto, a houſe was ſtruck and much damaged by the lightning from one of the clouds. In the accounts of the great eruption of Veſuvius in 1631, mention is made of the extenſive progreſs of the aſhes from Veſuvius, and of the damage done

by

by the ferilli, or volcanic lightning, which attended them in their courſe.

Our author in this place mentions a very extraordinary circumſtance, which happened near Sienna, on the Tuſcan ſtate, about eighteen hours after the commencement of the late eruption of Veſuvius on the 15th of June, although he adds, that phænomenon muſt have no relation to the eruption; it was communicated to him in the following words by the earl of Briſtol, biſhop of Derry, in a letter dated from Sienna, July 12, 1794: ‘ In the midſt of a moſt violent thunder-ſtorm, about a dozen ſtones of various weights and dimenſions fell at the feet of different people, men, women, and children; the ſtones are of a quality not found in any part of the Sienneſe territory; they fell about eighteen hours after the enormous eruption of Veſuvius, which circumſtance leaves a choice of difficulties in the ſolution of this extraordinary phænomenon: either theſe ſtones have been generated in this igneous maſs of clouds, which produced ſuch unuſual thunder, or, which is equally incredible, they were thrown from Veſuvius at a diſtance of at leaſt two hundred and fifty miles; judge then of its parabola.’ One of the largeſt ſtones, when entire, weighed upwards of five pounds. The outſide of every ſtone that was found, and aſcertained to have fallen from the cloud near Sienna, was evidently freſhly vitrified, and black, having every ſign of having paſſed through an extreme heat; when broken, the inſide was found of a light-grey colour mixed with black

black ſpots, and ſome ſhining particles, ſuppoſed to be pyrites. Stones of the ſame nature, at leaſt as far as the eye can judge of them, are frequently found on Mount Veſuvius; and ſhould ſimilar ſtones be found, with the ſame vitrified coat on them, on Mount Veſuvius, the queſtion would be decided in favour of Veſuvius, unleſs it could be proved that there had been, about the time of the fall of theſe ſtones in the Saneſe territory, ſome nearer opening of the earth, attended with an emiſſion of volcanic matter, which might very well happen, as the mountain of Radicofani, within fifty miles of Sienna, is certainly volcanic. The celebrated father Ambrogio Soldani, profeſſor of mathematics in the univerſity of Sienna, is printing there his diſſertation upon this extraordinary phænomenon; wherein, it is ſaid, he has decided that thoſe ſtones were generated in the air independently of volcanic aſſiſtance.

Until after the 7th of July, when the laſt cloud broke over Veſuvius, and formed a tremendous torrent of mud, which took its courſe acroſs the great road between Torre del Greco and the Torre dell' Annunziata, and deſtroyed many vineyards, the late eruption could not be ſaid to have finiſhed, although the force of it was over the 22d of June. The power of attraction in mountains is well known; but whether the attractive power of a volcanic mountain is greater than that of any other mountain, is a queſtion. During this laſt eruption, however, it appeared that every watery cloud was evidently attracted by Veſuvius, and the ſudden diſſo-

lution of those clouds left marks of their destructive power on the face of the country all round the basis of the volcano. Since the mouth of Vesuvius was enlarged, our author says he has seen a great cloud passing over it, and which not only was attracted, but was sucked in, and disappeared in a moment.

After every violent eruption of Mount Vesuvius, we read of damage done by a mephitic vapour, which coming from under the ancient lavas, insinuates itself into low places, such as the cellars and wells of the houses situate at the foot of the volcano. After the eruption of 1767, there were several instances, as in this, of people going into their cellars at Portici, and other parts of that neighbourhood, having been struck down by this vapour, and who would have expired if they had not been hastily removed. These occasional vapours, or *mofete*, are of the same quality as that permanent one in the Grotta del Cane, near the lake of Agnano, and which has been proved to be chiefly fixed air. The vapours, that in the volcanic language of Naples, are called *fumaroli*, are of another nature, and issue from spots all over the fresh and hot lavas while they are cooling; they are sulphureous and suffocating, so much so, that often the birds which are flying over them are overpowered, and fall down dead. These vapours deposit a crust of sulphur, or salts, particularly of sal ammoniac, on the scoriæ of the lava through which they pass; and the small crystals of which they are composed are often tinged with deep or pale yellow, with a bright red like cinnabar, and sometimes with green,

or

or an azure blue. After the late eruption, many pieces of the ſcoriæ of the freſh lava were found powdered with a lucid ſubſtance, exactly like the brighteſt ſteel or iron filings.

The firſt appearance of the mofete, after the late eruption, was on the 17th of June, when a peaſant going with an aſs to his vineyard, a little above the village of Reſina, in a narrow hollow way, the aſs dropped down, and ſeemed to be expiring; the peaſant was ſoon ſenſible of the mephitic vapour himſelf, and well knowing its fatal effects, dragged the animal out of its influence, and it ſoon recovered. This heavy vapour, when expoſed to the open air, does not riſe much more than a foot above the ſurface of the earth, but when it gets into a confined place, like a cellar or well, it riſes and fills as any other fluid would do; having filled a well, it riſes above it about a foot high, and then bending over, falls to the earth, on which it ſpreads, always preſerving its uſual level. Wherever this vapour iſſues, a wavering in the air is perceptible, like that which is produced by the burning of charcoal; and when it iſſues from a fiſſure near any plants or vegetables, the leaves of thoſe plants are ſeen to move, as if they were agitated by a gentle wind. It is extraordinary, that although there does not appear to be any poiſonous quality in this vapour, which in every reſpect reſembles fixed air, it ſhould prove ſo very fatal to the vineyards, ſome thouſand acres of which were deſtroyed by it after the late eruption: when it penetrates to the roots of the vines, it dries them up, and kills

the plant. A peafant in the neighbourhood of Refina, having fuffered by the mofete, which deftroyed his vineyards in the year 1767, and having obferved then that the vapour followed the laws of all fluids, made a narrow deep ditch all round his vineyard, which communicated with ancient lavas, and alfo with a deep cavern under one of them; the confequence of his well reafoned operation was, that although furrounded by thefe noxious vapours, which lay conftantly at the bottom of his ditch, they never entered his vineyard, and his vines were in a flourifhing ftate, while thofe of his neighbours were perifhing. Upwards of thirteen hundred hares, and many pheafants and partridges, overtaken by this vapour, were found dead within his Sicilian majefty's referved chafes in the neighbourhood of Vefuvius; and alfo many domeftic cats, who in their purfuit after this game fell victims to the mofete. A fhoal of fifh, of feveral hundred weight, having been obferved by fome fifhermen at Refina in great agitation on the furface of the fea, near fome rocks of an ancient lava that had run into the fea, they furrounded them with their nets, and took them all with eafe, and afterwards difcovered that they had been ftunned by the mephitic vapour, which at that time iffued forcibly from underneath the ancient lava into the fea.

The account of Sir William Hamilton is concluded by two remarks, which as they are curious I fhall infert:—

1. Within a mile of Caftel-a-mare, the mofete were ftill very active (on Sept. 2.) and particu-

larly

larly under the ſpot where the ancient town of Stabia was ſituated. The 24th of Auguſt, a young lad by accident falling into a well there that was dry, but full of the mephitic vapour, was immediately ſuffocated; there were no ſigns of any injury from the fall, as the well was ſhallow. This circumſtance called to our author's mind the death of the elder Pliny, who moſt probably loſt his life by the ſame ſort of mephitic vapours, on this very ſpot, and which are active after great eruptions of Veſuvius.

2. Mr. James, a Britiſh merchant, aſſured our author, that on Tueſday night, the 17th of June, which was the third day of the eruption of Mount Veſuvius, he was in a boat with a ſail, near Torre del Greco, when the minute aſhes, ſo often mentioned, fell thick; and that in the dark they emitted a pale light like phoſphorus, ſo that his hat, thoſe of the boatmen, and the part of the ſails that were covered with aſhes, were luminous. Others have mentioned the having ſeen a phoſphoric light on Veſuvius after this eruption; but until it was confirmed to him by Mr. James, he did not chuſe to ſay any thing about it *.'

* See Phil. Tranſ. for 1795, p. 73, &c.

## CHAP. XLVI.

### EARTHQUAKES.

*Connection between Earthquakes and Volcanoes.—Earthquakes caused by the Progress of Steam between the Strata of the Earth.—Signs of approaching Earthquakes.—Great Earthquake at Lisbon, in 1755.—Earthquakes in Calabria, in 1783.*

THE sudden explosions which take place from volcanoes, probably depend on the access of a quantity of water, which enters through some fissure communicating with the sea, or which is derived from other sources in the earth. If this mass of water is sufficiently great, it will extinguish the volcano; if not, it will be converted into steam, the expansive force of which far exceeds that of gunpowder. The elastic fluid, thus formed, either finds vent at the mouth of the volcano, or, if the superincumbent weight should be too great, it will force a passage between the strata of the earth, and occasion that undulatory but sometimes violent motion which is called an earthquake. From various facts demonstrative of the cohesion and elasticity of bodies, we are warranted in concluding, that the different strata of which the earth is composed will adhere together, and that a freer passage will be afforded to any intervening body between the strata than directly through them. If the confined fire acts directly under a province or town, it will heave

heave the earth perpendicularly upwards, and the ſhocks will be more ſudden and violent. If it acts at a diſtance, it will raiſe that tract obliquely, and the motion will be more oblique, undulatory, and tremulous.

The great earthquake at Liſbon, in 1755, was felt as far as Scotland, and from the phenomena which attended it, it was evident, that the ground had a waving motion from ſouth to north. All the oblong lakes, that lay from north to ſouth, were much agitated, the wave commencing at the ſouth end, whilſt all other lakes which lay acroſs, from eaſt to weſt, were much leſs affected.

The great diſtance to which earthquakes extend depends on the compreſſibility and elaſticity of the earth, which may be underſtood from the vibration of the walls of houſes, occaſioned by the paſſing of carriages in the adjacent ſtreets. Another inſtance is the vibration of ſteeples by the ringing of bells or guſts of wind. The Eddiſtone lighthouſe often vibrates from the force of the waves which beat againſt its foundation.

Previous to an eruption of Veſuvius the earth always trembles, and ſubterraneous exploſions are heard. On the 1ſt of November, 1755, the era ſo fatal to Liſbon, the iſland of Madeira was violently ſhaken by an earthquake, accompanied with ſubterraneous exploſions. So thoroughly convinced, indeed, are the inhabitants of volcanic countries of the connection between earthquakes and volcanoes, that when a great eruption takes place from a volcano,

they congratulate themſelves on having eſcaped an earthquake.

Earthquakes as well as volcanic eruptions are always preceded by a violent agitation of the ſea. Previous to the breaking out of Veſuvius, the ſea retires from the adjacent ſhores till the mountain is burſt open, and then it returns with ſuch impetuoſity as to overflow its uſual boundary. About an hour after the firſt ſhocks, which alarmed the city of Liſbon in 1755, the ſea was obſerved to come ruſhing towards the city like a torrent, though againſt both wind and tide; it roſe forty feet higher than was ever known, and as ſuddenly ſubſided. A ſhip, fifty leagues off at ſea, received ſo violent a ſhock as greatly to injure the deck, &c. The ſame effect was obſerved at Cadiz, and at a variety of ports throughout the Mediterranean, and, indeed, more or leſs, all over Europe.

That earthquakes are the effect of ſteam generated within the bowels of the earth, and that they are produced in the manner which has been deſcribed, appears highly probable from the quantities of ſteam and boiling water which have occaſionally been thrown up by volcanoes in different parts of the world. In 1631 and 1698 vaſt torrents of boiling water flowed from the crater of Veſuvius, previous to the eruption of fire: and what was, perhaps, ſtill more remarkable, many ſpecies of ſea-ſhells, in a calcined ſtate, were found on the brink of the crater, and alſo in the channel formed by the flood. The ſame thing happened at Ætna, in 1755, when a dreadful torrent of boiling water flowed

flowed from the crater at the time of an eruption of fire. Sir William Hamilton obſerves, that the ſea-ſhells emitted along with the water clearly indicate a communication with the ſea. All warm ſprings probably receive their heat from the action of pyrites, near which the water paſſes.

The following account of the great Liſbon earthquake is extracted from a volume of letters, publiſhed a few years ago by the reverend Mr. Davy:

'There never was a finer morning ſeen than the firſt of November (1755); the ſun ſhone out in its full luſtre; the whole face of the ſky was perfectly ſerene and clear, and not the leaſt ſignal or warning of that approaching event, which has made this once flouriſhing, opulent, and populous city, a ſcene of the utmoſt horror and deſolation, except only ſuch as ſerved to alarm, but ſcarcely left a moment's time to fly from the general deſtruction.

'It was on the morning of this fatal day, between the hours of nine and ten, that I was ſat down in my apartment, juſt finiſhing a letter, when the papers and table I was writing on began to tremble with a gentle motion, which rather ſurprized me, as I could not perceive a breath of wind ſtirring; whilſt I was reflecting with myſelf what this could be owing to, but without having the leaſt apprehenſion of the real cauſe, the whole houſe began to ſhake from the very foundation, which at firſt I imputed to the rattling of ſeveral coaches in the main ſtreet, which uſually paſſed that way, at this time, from Belem to the palace; but on hearken-

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ing more attentively, I was ſoon undeceived, as I found it was owing to a ſtrange frightful kind of noiſe under ground, reſembling the hollow diſtant rumbling of thunder; all this paſſed in leſs than a a minute, and I muſt confeſs I now began to be alarmed, as it naturally occurred to me, that this noiſe might poſſibly be the forerunner of an earthquake, as one I remembered, which had happened about ſix or ſeven years ago, in the Iſland of Madeira, commenced in the ſame manner, though it did little or no damage.

'Upon this I threw down my pen, and ſtarted upon my feet, remaining a moment in ſuſpenſe, whether I ſhould ſtay in the apartment, or run into the ſtreet, as the danger in both places ſeemed equal; and ſtill flattering myſelf that this tremor might produce no other effects than ſuch inconſiderable ones as had been felt at Madeira; but in a moment I was rouſed from my dream, being inſtantly ſtunned with a moſt horrid craſh, as if every edifice in the city had tumbled down at once. The houſe I was in ſhook with ſuch violence, that the upper ſtories immediately fell, and though my apartment (which was the firſt floor) did not then ſhare the ſame fate, yet every thing was thrown out of its place in ſuch a manner, that it was with no ſmall difficulty I kept my feet, and expected nothing leſs than to be ſoon cruſhed to death, as the walls continued rocking to and fro in the frightfulleſt manner, opening in ſeveral places, large ſtones falling down on every ſide from the cracks, and the ends of moſt of the rafters ſtarting out from the roof,

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To add to this terrifying ſcene, the ſky in a moment became ſo gloomy, that I could now diſtinguiſh no particular object; it was an Egyptian darkneſs indeed, ſuch as might be felt; owing, no doubt, to the prodigious clouds of duſt and lime, raiſed from ſo violent a concuſſion, and as ſome reported, to ſulphureous exhalations, but this I cannot affirm; however, it is certain I found myſelf almoſt choaked for near ten minutes.

'As ſoon as the gloom began to diſperſe, and the violence of the ſhock ſeemed pretty much abated, the firſt object I perceived in the room was a woman ſitting on the floor, with an infant in her arms, all covered with duſt, pale and trembling; I aſked her how ſhe got hither: but her conſternation was ſo great that ſhe could give me no account of her eſcape; I ſuppoſe, that when the tremor firſt began, ſhe ran out of her own houſe, and finding herſelf in ſuch imminent danger from the falling of ſtones, retired into the door of mine, which was almoſt contiguous to her's, for ſhelter, and when the ſhock increaſed, which filled the door with duſt and rubbiſh, ran up ſtairs into my apartment, which was then open: be it as it might, this was no time for curioſity. I remember the poor creature aſked me, in the utmoſt agony, if I did not think that the world was at an end; at the ſame time ſhe complained of being choaked, and begged for God's ſake I would procure her a little drink; upon this I went to a cloſet where I kept a large jar with water (which you know is ſometimes a pretty ſcarce commodity in Liſbon) but finding it broken in pieces, I told her

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ſhe muſt not now think of quenching her thirſt, but ſaving her life, as the houſe was juſt falling on our heads, and if a ſecond ſhock came, would certainly bury us both; I bade her take hold of my arm, and that I would endeavour to bring her into ſome place of ſecurity.

'I ſhall always look upon it as a particular providence, that I happened on this occaſion to be undreſſed, for had I dreſſed myſelf, as I propoſed, when I got out of bed, in order to breakfaſt with a friend, I ſhould, in all probability, have run into the ſtreet at the beginning of the ſhock, as the reſt of the people in the houſe did, and conſequently have had my brains daſhed out, as every one of them had; however, the imminent danger I was in did not hinder me from conſidering that my preſent dreſs, only a gown and ſlippers, would render my getting over the ruins almoſt impracticable: I had, therefore, ſtill preſence of mind enough left to put on a pair of ſhoes and a coat, the firſt that came in my way, which was every thing I ſaved, and in this dreſs I hurried down ſtairs, the woman with me, holding by my arm, and made directly to that end of the ſtreet which opens to the Tagus, but finding the paſſage this way entirely blocked up with the fallen houſes to the height of their ſecond ſtories, I turned back to the other end which led into the main ſtreet (the common thoroughfare to the palace) and having helped the woman over a vaſt heap of ruins, with no ſmall hazard to my own life, juſt as we were going into the ſtreet, as there was one part I could not well climb over without the aſſiſtance

of my hands, as well as feet, I desired her to let go her hold, which she did, remaining two or three feet behind me, at which time there fell a vast stone, from a tottering wall, and crushed both her and the child in pieces: so dismal a spectacle at any other time would have affected me in the highest degree, but the dread I was in of sharing the same fate myself, and the many instances of the same kind which presented themselves all around, were too shocking to make me dwell a moment on this single object.

'I had now a long narrow street to pass, with the houses on each side four or five stories high, all very old, the greater part already thrown down, or continually falling, and threatening the passengers with inevitable death at every step, numbers of whom lay killed before me, or what I thought far more deplorable—so bruised and wounded that they could not stir to help themselves. For my own part, as destruction appeared to me unavoidable, I only wished I might be made an end of at once, and not have my limbs broken, in which case I could expect nothing else but to be left upon the spot, lingering in misery, like these poor unhappy wretches, without receiving the least succour from any person.

'As self-preservation, however, is the first law of nature, these sad thoughts did not so far prevail, as to make me totally despair. I proceeded on as fast as I conveniently could, though with the utmost caution, and having at length got clear of this horrid passage, I found myself safe and unhurt in the large

large open ſpace before St. Paul's church, which had been thrown down a few minutes before, and buried a great part of the congregation, that was generally pretty numerous, this being reckoned one of the moſt populous pariſhes in Liſbon. Here I ſtood ſome time, conſidering what I ſhould do, and not thinking myſelf ſafe in this ſituation, I came to the reſolution of climbing over the ruins of the weſt end of the church, in order to get to the river ſide, that I might be removed, as far as poſſible, from the tottering houſes, in caſe of a ſecond ſhock.

'This, with ſome difficulty, I accompliſhed, and here I found a prodigious concourſe of people, of both ſexes, and of all ranks and conditions, among whom I obſerved ſome of the principal canons of the patriarchal church, in their purple robes and rochets, as theſe all go in the habit of biſhops; ſeveral prieſts who had run from the altars in their ſacerdotal veſtments in the midſt of their celebrating maſs; ladies half dreſſed, and ſome without ſhoes; all theſe, whom their mutual dangers had here aſſembled as to a place of ſafety, were on their knees at prayers, with the terrors of death in their countenances, every one ſtriking his breaſt, and crying out inceſſantly, *Miſerecordia meu Dios.*

'In the midſt of our devotions, the ſecond great ſhock came on, little leſs violent than the firſt, and completed the ruin of thoſe buildings which had been already much ſhattered. The conſternation now became ſo univerſal, that the ſhrieks and cries of *Miſerecordia* could be diſtinctly heard from the top of St. Catherine's hill, at a conſiderable diſtance

off, whither a vaſt number of people had likewiſe retreated; at the ſame time we could hear the fall of the pariſh church there, whereby many perſons were killed on the ſpot, and others mortally wounded. You may judge of the force of this ſhock, when I inform you, it was ſo violent, that I could ſcarce keep on my knees, but it was attended with ſome circumſtances ſtill more dreadful than the former.—On a ſudden I heard a general outcry, 'The ſea is coming in, we ſhall be all loſt.'—Upon this, turning my eyes towards the river, which in that place is near four miles broad, I could perceive it heaving and ſwelling in a moſt unaccountable manner, as no wind was ſtirring; in an inſtant there appeared, at ſome ſmall diſtance, a large body of water, riſing like a mountain; it came on foaming and roaring, and ruſhed towards the ſhore with ſuch impetuoſity, that we all immediately ran for our lives, as faſt as poſſible; many were actually ſwept away, and the reſt above their waiſt in water at a good diſtance from the banks. For my own part, I had the narroweſt eſcape, and ſhould certainly have been loſt, had I not graſped a large beam that lay on the ground, till the water returned to its channel, which it did almoſt at the ſame inſtant, with equal rapidity. As there now appeared at leaſt as much danger from the ſea as the land, and I ſcarce knew whither to retire for ſhelter, I took a ſudden reſolution of returning back with my cloaths all dropping, to the area of St. Paul's: here I ſtood ſome time, and obſerved the ſhips tumbling and toſſing about, as in a violent ſtorm; ſome had broken

ken their cables, and were carried to the other side of the Tagus; others were whirled round with incredible swiftness; several large boats were turned keel upwards; and all this without any wind, which seemed the more astonishing. It was at the time of which I am now speaking, that the fine new quay, built entirely of rough marble, at an immense expence, was entirely swallowed up, with all the people on it, who had fled thither for safety, and had reason to think themselves out of danger in such a place; at the same time a great number of boats and small vessels, anchored near it (all likewise full of people, who had retired thither for the same purpose) were all swallowed up, as in a whirlpool, and never more appeared.

'This last dreadful incident I did not see with my own eyes, as it passed three or four stones throws from the spot where I then was, but I had the account as here given from several masters of ships, who were anchored within two or three hundred yards of the quay, and saw the whole catastrophe. One of them in particular informed me, that when the second shock came on, he could perceive the *whole* city waving backwards and forwards, like the sea when the wind first begins to rise; that the agitation of the earth was so great even under the river, that it threw up his large anchor from the mooring, which swam, as he termed it, on the surface of the water; that immediately upon this extraordinary concussion, the river rose at once near twenty feet, and in a moment subsided; at which instant he saw the quay, with the whole concourse

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of people upon it, sink down, and at the same time every one of the boats and vessels that were near it were drawn into the cavity, which he supposes instantly closed upon them, inasmuch as not the least sign of a wreck was ever seen afterwards. This account you may give full credit to, for as to the loss of the vessels, it is confirmed by every body; and with regard to the quay, I went myself a few days after, to convince myself of the truth, and could not find even the ruins of a place, where I had taken so many agreeable walks, as this was the common rendezvous of the factory in the cool of the evening. I found it all deep water, and in some parts scarcely to be fathomed.

'This is the only place I could learn which was swallowed up in or about Lisbon, though I saw many large cracks and fissures in different parts, and one odd phenomenon I must not omit, which was communicated to me by a friend who has a house and wine-cellars on the other side of the river, viz. that the dwelling-house being first terribly shaken, which made all the family run out, there presently fell down a vast high rock near it, that upon this the river rose and subsided in the manner already mentioned, and immediately a great number of small fissures appeared in several contiguous pieces of ground, whence there spouted out like a *jet d' eau* a large quantity of fine white sand, to a prodigious height.

'I had not been long in the area of St. Paul's, when I felt the third shock, which though somewhat less violent than the two former, the sea rushed in

again, and retired with the fame rapidity, and I remained up to my knees in water, though I had gotten upon a fmall eminence at fome diftance from the river, with the ruins of feveral intervening houfes to break its force. At this time I took notice the waters retired fo impetuoufly, that fome veffels were left quite dry, which rode in feven fathom water: the river thus continued alternately rufhing on and retiring feveral times together, in fuch fort, that it was juftly dreaded Lifbon would now meet the fame fate, which a few years ago had befallen the city of * Lima.

'Perhaps you may think the prefent doleful fubject here concluded; but, alas! the horrors of the firft of November, are fufficient to fill a volume. As foon as it grew dark, another fcene prefented itfelf little lefs fhocking than thofe already defcribed—the whole city appeared in a blaze, which was fo bright that I could eafily fee to read by it. It may be faid, without exaggeration, it was on fire at leaft in an hundred different places at once, and thus continued burning for fix days together, without intermiffion, or the leaft attempt being made to ftop its progrefs.

'I could never learn, that this terrible fire was owing to any fubterraneous eruption, as fome reported, but to three caufes, which all concurring at the fame time, will naturally account for the prodigious havock it made; the firft of November being All Saints Day, a high feftival among the Portu-

* This happened in 1746.

guese, every altar in every church and chapel (some of which have more than twenty) was illuminated with a number of wax tapers and lamps, as customary; these setting fire to the curtains and timber work that fell with the shock, the conflagration soon spread to the neighbouring houses, and being there joined with the fires in the kitchen chimnies, increased to such a degree, that it might easily have destroyed the whole city, though no other cause had concurred, especially as it met with no interruption.

'But what would appear incredible to you, were the fact less public and notorious, is, that a gang of hardened villains, who had been confined, and got out of prison when the wall fell, at the first shock, were busily employed in setting fire to those buildings, which stood some chance of escaping the general destruction.

'The fire, by some means or other, may be said to have destroyed the whole city, at least every thing that was grand or valuable in it; and the damage on this occasion is not to be estimated.

'The whole number of persons that perished, including those who were burnt, or afterwards crushed to death whilst digging in the ruins, is supposed, on the lowest calculation, to amount to more than sixty thousand; and though the damage in other respects cannot be computed, yet you may form some idea of it, when I assure you, that this extensive and opulent city, is now nothing but a vast heap of ruins, that the rich and poor are at present upon a level, some thousands of families which but

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the day before had been easy in their circumstances, being now scattered about in the fields, wanting every conveniency of life, and finding none able to relieve them.

'A few days after the first consternation was over, I ventured down into the city, by the safest ways I could pick out, to see if there was a possibility of getting any thing out of my lodgings, but the ruins were now so augmented by the late fire, that I was so far from being able to distinguish the individual spot where the house stood, that I could not even distinguish the street, amidst the mountains of stone and rubbish which rose on every side. Some days after, I ventured down again with several porters, who, having long plied in these parts of the town, were well acquainted with the situation of particular houses; by their assistance, I at last discovered the spot; but was soon convinced, that to dig for any thing there, besides the danger of such an attempt, would never answer the expence.

'On both the times when I attempted to make this fruitless search, especially the first, there came such an intolerable stench from the dead bodies, that I was ready to faint away, and though it did not seem so great this last time, yet it had nearly been more fatal to me, as I contracted a fever by it, but of which, God be praised, I soon got the better. However, this made me so cautious for the future, that I avoided passing near certain places, where the stench was so excessive that people began to dread an infection: a gentleman told me, that going into the town a few days after the earthquake,

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he ſaw ſeveral bodies lying in the ſtreets, ſome horribly mangled, as he ſuppoſed, by the dogs, others half burnt, ſome quite roaſted; and that in certain places, particularly near the doors of churches, they lay in vaſt heaps piled one upon another.'

The year 1783 was fatally marked by the deſolation of ſome of the moſt fertile, moſt beautiful, and moſt celebrated provinces of Europe. The two Calabrias, with a part of Sicily, were doomed to be a ſcene of the moſt tremendous, and the moſt fatal earthquakes that ever were known, even in thoſe volcanic regions. The firſt ſhock happened about noon, on the 5th of February, and was ſo violent as to involve almoſt the whole of Calabria in ruin. This was but the commencement of a ſucceſſion of earthquakes, which beginning from the city of Amantea, on the coaſt of the Tyrrhene ſea, proceeded along the weſtern coaſt to Cape Spartivento, and up the eaſtern as far as Cape D'Alice; during the whole of which ſpace not a town was left undeſtroyed.

During two years repeated ſhocks continued to agitate the affrighted minds of the inhabitants of Calabria and Sicily, but the principal miſchiefs aroſe in the months of February and March in the firſt year. For ſeveral months the earth continued in an unceaſing tremor, which at certain intervals increaſed to violent ſhocks, ſome of which were beyond deſcription dreadful. Theſe ſhocks were ſometimes horizontal, whirling like a vortex; and ſometimes by pulſations or beating from the bottom upwards,

and were at times ſo violent that the heads of the largeſt trees almoſt touched the ground on either ſide. The rains, during a great part of the time, were continual and violent, often accompanied with lightning, and furious guſts of wind. All that part of Calabria, which lay between the 38th and 39th degrees, aſſumed a new appearance. Houſes, churches, towns, cities, and villages, were buried in one promiſcuous ruin. Mountains were detached from their foundations, and carried to a conſiderable diſtance *. Rivers diſappeared from their beds, and again returned and overflowed the adjacent country †. Streams of water ſuddenly guſhed out of the ground, and ſprang to a conſiderable height. Large pieces of the ſurface of the plain, ſeveral

* Sir William Hamilton, whoſe ardent and laudable ſpirit of inquiry occaſioned his viſiting Calabria and Sicily during this calamitous ſeaſon, accounts for the removal of a mountain of about two hundred and fifty feet in heighth, and about four hundred feet in diameter at its baſis, from the different nature of its inferior and ſuperior ſtrata. The under part being more ſolid and compact, was more ſtrongly acted upon by the violent motion of the earth, and the volcanic exhalations, which drove it to the diſtance of ſome hundred yards from its original ſcite, where it lay in confuſed blocks, after having left the ſuperior ſtratum, which, with its trees and vineyards, was carried in another direction to the diſtance of four miles.

† The ſame philoſopher accounts for this phenomenon by ſuppoſing the firſt impulſe of the earthquake to have come from the bottom upwards, which raiſing the ſurface of the ground, the rivers which are not deep muſt naturally diſappear; but the earth returning again with violence to its former level, the rivers muſt as naturally return and overflow their banks; at the ſame time the boggy grounds being ſuddenly depreſſed, would force out the water which lay hid under their ſurface.

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acres in extent, were carried five hundred feet from their former situation down into the bed of the river, and left standing at nearly the distance of a mile, surrounded by large plantations of olives and mulberry trees, and corn growing as well upon them as upon the ground from which they were separated. Amidst these scenes of devastation, the escapes of some of the unhappy sufferers is extremely wonderful. Some of the inhabitants of houses which were thrown to a considerable distance, were dug out from their ruins unhurt. But these instances were few, and those who were so fortunate as to preserve their lives in such situations, were content to purchase existence at the expence of broken limbs and the most dreadful contusions.

During this calamitous scene, it is impossible to conceive the horrors and wretchedness of the unhappy inhabitants. The jaws of death were opened to swallow them up; ruin had seized all their possessions, and those dear connections to which they might have looked for consolation in their sorrows, were for ever buried in the merciless abyss. All was ruin and desolation. Every countenance indicated the extremity of affliction and despair; and the whole country formed a wide scene of undescribable horror.

One of the most remarkable towns which was destroyed was Casal Nuova, where the Princess Gerace Grimaldi, with more than four thousand of her subjects, perished in the same instant. An inhabitant happening to be on the summit of a neighbouring hill at the moment of the shock, and

looking earnestly back to the residence of his family, could see no other remains of it than a white cloud which proceeded from the ruins of the houses. At Bagnara, about three thousand persons were killed, and not fewer at Radicina and Palma. At Terra Nuova four thousand four hundred perished, and rather more at Semniari. The inhabitants of Scilla escaped from their houses on the celebrated rock of that name, and, with their prince, descended to a little harbour at the foot of the hill; but, in the course of the night, a stupendous wave, which is said to have been driven three miles over land, on its return swept away the unfortunate prince, with two thousand four hundred and seventy-three of his subjects. It is computed that not less than forty thousand persons perished by this earthquake.

# BOOK VII.

## OF WATER.

### CHAP. I.

### OF WATER IN GENERAL.

*Water a Compound Body.—Three States of Water.—Water in a fluid State.—Florentine Experiment.—Vapour.—Experiments ascertaining the Force of Vapour.—Steam Engine.—Ice.—Phenomena of Freezing.—Of Thawing.—Water expanded in the State of Ice.—Immense Force exerted by Water on passing to that State.—Why Ice is not perfectly transparent.*

WATER was univerſally conſidered as a ſimple elementary ſubſtance till the chemiſts of the preſent age proved, by experiments, the ſubſtance of which has been ſtated in a preceding volume *, that it is in reality a compound body. Its principles have been aſcertained both by compoſition and decompoſition; and one hundred parts of water are found to conſiſt of eighty-five parts of oxygen, and fifteen of hydrogen, or the baſis of inflammable air.

* Book V. Chap. I.

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This very useful and necessary fluid presents itself to our notice in three distinct forms, namely, in its liquid state, in the state of vapour or steam, and lastly in its frozen state. Of these I shall speak in their order.

Water, when pure and in its fluid state, is transparent, colourless, and without smell. It adheres to most bodies which come in contact with it, it pervades porous substances, dissolves gummy and saline matters, and extinguishes fire.

Water, when fluid is not in its most simple state, for its fluidity depends on a certain quantity of caloric, or the matter of heat, which enters into combination with it, and insinuating itself between the particles of the water, renders them capable of moving in all directions.

We are supplied with water either from the atmosphere, whence it descends in the form of rain, hail, or snow, or from the earth which sends it forth in springs and rivulets. In the former case the watery exhalations drawn from the sea, and the surface of the earth by the sun's heat, form clouds, whose particles being afterwards condensed, fall back again in showers. In the latter, the water which falls on the tops of mountains, and other lofty situations, penetrates the earth, and, after passing downwards, breaks forth at some fissure or aperture at a distance from its source.

The quantity of water attracted from the surface of the globe is almost incredible. Dr. Halley has calculated that portion which is yielded by the sea, to be at the rate of one cubic inch from

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every ten inches of surface in twelve hours *. To form an adequate idea of this, let us suppose only half the globe to be covered by the sea. The whole surface of the earth being about 25,797,278 leagues, that of the sea will consequently be 12,898,639. Supposing the evaporation which takes place in twelve hours to be that above mentioned, without having any regard to what is evaporated from the whole of the land, or from the sea during the other twelve hours, it will be found that the atmosphere has taken up no less than 20,302,535,177,834, or more than twenty millions of millions of cubic feet of water; an enormous quantity, and much more than sufficient to supply all the rivers that intersect the different quarters of the globe †.

What particularly distinguishes water, and those fluids which are of a similar consistence, and in common language are termed liquids, from those subtile fluids which were treated of at large in the preceding volume, is, that the former are not, like the others, possessed of that surprizing elasticity

* See Bishop Watson's Calculation, vol. i. p. 122.

† There will possibly be apparent, in this part of the work, some degree of repetition when compared with what was said of vapour in the first book. It was then necessary to speak of vapour, in explanation of the properties of heat; it is now necessary to treat of it in connection with the fluid of which it is usually formed; and I conceive it better to do this, with the risk of some repetition, than to refer to a former volume, both because it will serve more firmly to impress on the minds of young readers some of the most important doctrines of philosophy: and because what may now appear as repetition, is, in this place, mixed with new facts, which could not be previously introduced.

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which admits of the volume of fluid being condensed into a small compass; but, on the contrary, may be considered as incapable of compression, or at least are compressible in a very slight degree. The Florentine academicians filled a globe of gold with water, and compressed it with immense force; the first effect of this compression was, that the ball was considerably heated by the emission of latent heat from the water, and afterwards the fluid forced its way through the pores of the gold, or through certain cavities, and appeared in drops on the external surface. The conclusion, however, which was hastily drawn from this experiment, that water, in its liquid state, is absolutely void of all elasticity, is not warrantable. Since other experiments shew that water as well as mercury will yield, in a certain degree, to the pressure of the air in a condensing machine, as Mr. Canton proved by including it in a glass vessel, with a narrow neck or stem nicely graduated; its condensation appears proportioned to the force, and as soon as the pressure of the air is removed, the fluid will be observed gradually to recover its accustomed dimensions.

When water becomes heated to a degree beyond that of the air upon its surface, the matter of heat, which has a constant propensity to diffuse itself equally through all bodies with which it is in contact, rises and carries with it part of the water, which it converts into an elastic fluid or vapour. Until the water, however, arrives at the boiling point, the evaporation is very gradual; but when this happens it becomes very rapid, and the part of

the

the water which is moſt heated, being converted into vapour, riſes ſuddenly to the ſurface, and occaſions conſiderable agitation.

Ebullition requires a determined degree of heat, becauſe the ſteam cannot be formed within the water, unleſs it is ſtrong enough to overcome the actual preſſure of the fluid and air incumbent on it. But in ordinary evaporation, the vapour is formed at the ſurface of the water; and has therefore no other preſſure to overcome than that of the atmoſphere. The elaſtic fluid, however, which is formed by ordinary evaporation is different from that produced by ebullition, for the latter always returns to the ſtate of water by a diminution of temperature, whereas the former is reduced almoſt to the ſtate of a permanently elaſtic fluid by mixture with air.

We find that all fluids boil more eaſily in proportion as the preſſure of the atmoſphere is removed; whether this is effected by aſcending a mountain, or making uſe of the air pump. M. Lavoiſier ſays, that if the weight of the atmoſphere was only equal to between twenty or twenty-four inches of a column of mercury, inſtead of twenty-eight inches, we ſhould never be able to obtain æther in a liquid ſtate, at leaſt in ſummer; and that the formation of æther muſt conſequently be impoſſible upon mountains of a moderate degree of elevation, without employing extraordinary means of compreſſion for its condenſation. Upon the whole, it appears moſt probable that all bodies are capable of exiſting in a ſolid, a liquid, and an aeriform ſtate; that the

first is the most simple state of all bodies, and that the two others depend on combinations with different quantities of the matter of heat, of which the aeriform state requires by far the most.

Vapour, as it first rises from boiling water, is invisible, but as it mixes with the air it is deprived of part of its heat, returns to its fluid form, and the very minute drops of water which are produced ascend in a copious cloud of a white or light-grey colour. Vapour is the more readily discernable in proportion to the coldness and humidity of the atmosphere. The cloudy appearance of steam is occasioned by the difficulty with which its particles are separated and dissolved in the atmosphere; the difficulty is increased in proportion to the coldness and humidity of the air, and this is the reason that the moisture exhaled with the breath, is visible in winter and not in summer.

It was stated in a former volume, that the combination of the matter of heat or caloric, with the particles of water, in that degree which constitutes steam, rarifies them so exceedingly, as to occasion them to occupy a space some hundred times greater than the original bulk of the fluid, and it is that also which volatilizes and enables them to ascend through the air, and to overcome its resistance.

But when steam is exposed to a still greater degree of heat, its volume is augmented still more considerably. That heat which makes water boil, and which rarifies it only one twenty-sixth, rarifies its vapour to eighteen hundred times the bulk of the water which produced it. This may be very readily

 demonstrated,

demonſtrated, by taking a glaſs tube, at one end of which is a bulb of two inches in diameter, and dropping into it a ſingle drop of water, the diameter of which we will ſuppoſe to be one-tenth of an inch. The ſquares of theſe two ſpheres, with regard to each other, will be as 1800 are to one. Upon heating the bulb of the tube over the flame of a ſpirit lamp, the air will firſt be expelled, and afterwards the drop of water will be converted into ſteam, and take poſſeſſion of the whole of the bulb; as may be proved by plunging the mouth of the tube into cold water, and ſuffering the ſteam within the bulb to return to its fluid ſtate. In this caſe, the preſſure of the atmoſphere will cauſe the water to ruſh into the tube, and to occupy that ſpace within the bulb, which before was occupied by the vapour, and thus the fact will be aſcertained.

If, however, any obſtacle is oppoſed to the expanſive force of ſteam, the heat augments its reſiſtance in a degree proportionate to the augmentation of its volume. The power of reſiſtance afforded by the vapour of water is prodigious, and has of late years been made ſubſervient to ſome mechanical purpoſes of the greateſt importance. Muſchenbrook has proved by experiment, that the force of gunpowder is feeble, when compared to that of riſing ſteam. An hundred and forty pounds of gunpowder blew up a weight of thirty thouſand pounds; but on the other hand, an hundred and forty pounds of water, converted by heat into ſteam, lifted a weight of ſeventy-ſeven thouſand pounds, and would lift a

much

much greater, if there were means of giving the ſteam greater heat with ſafety; for the hotter the ſteam the greater is its force.

The ſteam-engine, to which I had formerly occaſion ſlightly to advert*, is a machine which may be, and is occaſionally applied to various mechanical purpoſes where great force is required, but which has *hitherto* been principally uſed to clear mines from water, and to raiſe water to a proper height for the ſupply of cities. In theſe caſes, the expanſive power of ſteam is ſo managed as to operate on immenſe water pumps, which could not conveniently be worked by any other means. In order to give the reader a ſuperficial idea of this machine, let us imagine a common pump prepared, and that we want to move the handle of this pump upwards by the force of ſteam only. In the firſt place, let us ſuppoſe, that the handle of the pump, or ſomething connected to it, was ſo contrived as to admit of being inſerted in the barrel of a gun, or ſome cylindrical tube, ſet upright over a cauldron containing boiling water. Next let us ſuppoſe, that the ſteam could be admitted into the tube, through the touch-hole, and ſo confined as to paſs only by that way. Now as the fire begins to dilate the ſteam, a part of it will enter the tube by the touch-hole, and this will preſs up the pump, which is ſuppoſed to be ſo fitted to the tube as to prevent any part of the ſteam from eſcaping. In this way the pump handle would be driven quite out at the mouth of the tube,

* See vol. i. p. 110.

but,

but let us imagine, that before this can happen a valve is opened, which allows a ſmall quantity of cold water to be ſpouted into the tube, which effectually and inſtantaneouſly deſtroys, or, more properly, condenſes the ſteam. The tube being now left empty, there is nothing to counteract the preſſure of the atmoſphere, which again forces down the handle into the tube, into which no ſteam is permitted to enter, on account of a valve which now ſtops the touch hole below; but when the handle is thus preſſed down, the valve below is again opened, and new ſteam entering again preſſes the handle upward; when the handle comes near the top, the ſteam is again cooled and condenſed as before, and the handle is again preſſed down by the weight of the atmoſphere. In this manner it is alternately driven upwards and downwards by the expanſive power of the ſteam and the preſſure of the external air, and works the pump with unwearied aſſiduity.

Though the principle, however, is plain, the machinery is complex in the ſteam engine; but the annexed plate IV. will probably render it tolerably intelligible.

In fig. 1. A repreſents the fire-place under the boiler, for the boiling of the water, and the aſh-hole below it.

B, the boiler, filled with water about three feet above the bottom, made of iron plates.

C, the ſteam pipe, through which the ſteam paſſes from the boiler into the receiver.

D, the receiver, a cloſe iron veſſel, in which is the regulator or ſteam-cock, which opens and ſhuts the hole of communication at each ſtroke.

E, the communication pipe between the receiver and the cylinder; it riſes five or ſix inches up, in the inſide of the cylinder bottom, to prevent the injected water from deſcending into the receiver.

F, the cylinder, of caſt iron, about ten feet long, bored ſmooth in the inſide; it has a broad flanch in the middle on the outſide, by which it is ſupported when hung in the cylinder-beams.

G, the piſton, made to fit the cylinder exactly: it has a flanch riſing four or five inches upon its upper ſurface, between which and the ſide of the cylinder a quantity of junk or oakum is ſtuffed, and kept down by weights, to prevent the entrance of air or water and the eſcaping of ſteam.

H, the chain and piſton ſhank, by which it is connected to the working beam.

I I, the working beam or lever: it is made of two or more large logs of timber, bent together at each end, and kept at the diſtance of eight or nine inches from each other in the middle by the gudgeon, as repreſented in the plate. The arch-heads, I I, at the ends, are for giving a perpendicular direction to the chains of the piſton and pump-rods.

K, the pump-rod which works in the ſucking pump

L, and draws the water from the bottom of the pit to the ſurface.

M, a

M, a ciſtern, into which the water drawn out of the pit is conducted by a trough, ſo as to keep it always full; and the ſuperfluous water is carried off by another trough.

N, the jack-head pump, which is a ſucking-pump wrought by a ſmall lever or working-beam, by means of a chain connected to the great beam or lever near the arch *g* at the inner end, and the pump rod at the outer end. This pump commonly ſtands near the corner of the front of the houſe, and raiſes the column of water up to the ciſtern O, into which it is conducted by a trough.

O, the jack-head ciſtern for ſupplying the injection, which is always kept full by the pump N; it is fixed ſo high as to give the jet a ſufficient velocity into the cylinder when the cock is opened. This ciſtern has a pipe on the oppoſite ſide for conveying away the ſuperfluous water.

P P, the injection-pipe, of three or four inches diameter, which turns up in a curve at the lower end, and enters the cylinder bottom; it has a thin plate of iron upon the end *a*, with three or four adjutage holes in it, to prevent the jet of cold water of the jack-head ciſtern from flying up againſt the piſton, and yet to condenſe the ſteam each ſtroke, when the injection-cock is open.

*e*, a valve upon the upper end of the injection-pipe within the ciſtern, which is ſhut when the engine is not working, to prevent any waſte of the water.

*f*, a ſmall pipe which branches off from the injection-pipe, and has a ſmall cock to ſupply the piſton with a little water to keep it air-tight.

Q, the working plug, ſuſpended by a chain to the arch *g* of the working beam. It is uſually a heavy piece of timber, with a ſlit vertically down its middle, and holes bored horizontally through it, to receive pins for the purpoſe of opening and ſhutting the injection and ſteam cocks, as it aſcends and deſcends by the motion of the working beam.

*h*, the handle of the ſteam-cock or regulator. It is fixed to the regulator by a ſpindle which comes up through the top of the receiver. The regulator is a circular plate of braſs or caſt iron, which is moved horizontally by the handle *h*, and opens or ſhuts the communication at the lower end of the pipe E within the receiver. It is repreſented in the plate by a circular dotted line.

*i i*, the ſpanner, which is a long rod or plate of iron for communicating motion to the handle of the regulator, to which it is fixed by means of a ſlit in the latter, and ſome pins put through to faſten it.

*k l*, the vibrating lever, called the Y, having the weight *k* at one end and two legs at the other end. It is fixed to an horizontal axis, moveable about its center-pins or pivots *m n*, by means of the two ſhanks *o p* fixed to the ſame axis, which are alternately thrown backwards and forwards by means of two pins in the working plug; one pin on the outſide depreſſing the ſhank *o*, throws the loaded end *k* of the Y from the cylinder into the poſition repreſented in the plate, and cauſes the leg

*l* to

*l* to ſtrike againſt the end of the ſpanner, which, forcing back the handle of the regulator or ſteam cock, opens the communication, and permits the ſteam to fly into the cylinder. The piſton immediately riſing by the admiſſion of the ſteam, the working beam I I riſes; which alſo raiſes the working-plug, and another pin which goes through the ſlit raiſes the ſhank *p*, which throws the end *k* of the Y towards the cylinder, and, ſtriking the end of the ſpanner, forces it forward, and ſhuts the regulator ſteam-cock.

*q r*, the lever for opening and ſhutting the injection cock, called the F. It has two toes for its center, which take between them the key of the injection cock. When the working-plug has aſcended nearly to its greateſt height, and ſhut the regulator, a pin catches the end *q* of the F and raiſes it up, which opens the injection-cock, admits a jet of cold water to fly into the cylinder, and, condenſing the ſteam, makes a vacuum; then the preſſure of the atmoſphere bringing down the piſton in the cylinder, and alſo the plug-frame, another pin fixed in it catches the end of the lever in its deſcent, and, by preſſing it down, ſhuts the injection-cock, at the ſame time the regulator is opened to admit ſteam, and ſo on alternately; when the regulator is ſhut the injection is open, and when the former is open the latter is ſhut.

R, the hot-well, a ſmall ciſtern made of planks, which receives all the waſte water from the cylinder.

S, the fink-pit to convey away the water which is injected into the cylinder at each ftroke. Its upper end is even with the infide of the cylinder bottom, its lower end has a lid or cover moveable on a hinge, which ferves as a valve to let out the injected water, and fhuts clofe each ftroke of the engine, to prevent the water being forced up again when the vacuum is made.

T, the feeding-pipe, to fupply the boiler with water from the hot-well. It has a cock to let in a large or fmall quantity of water, as occafion requires, to make up for what is evaporated; it goes nearly down to the boiler bottom.

U, two gage cocks, the one larger than the other, to try when a proper quantity of water is in the boiler: upon opening the cocks, if one gives fteam and the other water, it is right; if they both give fteam, there is too little water in the boiler; and if they both give water, there is too much.

W, a plate which is fcrewed on to a hole on the fide of the boiler, to allow a paffage into the boiler for the convenience of cleaning or repairing it.

X, the fteam-clack or puppet valve, which is a brafs valve on the top of a pipe opening into the boiler, to let off the fteam when it is too ftrong. It is loaded with lead, at the rate of one pound to an inch fquare; and when the fteam is nearly ftrong enough to keep it open, it will do for the working of the engine.

*f*, the fnifting valve, by which the air is difcharged from the cylinder each ftroke, which was admitted

with

with the injection, and would otherwise obstruct the due operation of the engine.

*t t*, the cylinder-beams; which are strong joists going through the house for supporting the cylinder.

*v*, the cylinder cap of lead, soldered on the top of the cylinder, to prevent the water upon the piston from flashing over when it rises too high.

*w*, the waste-pipe, which conducts the superfluous water from the top of the cylinder to the hot-well.

*x x*, iron bars, called the catch-pins, fixed horizontally through each arch head, to prevent the beam descending too low in case the chain should break.

*y y*, two strong wooden springs, to weaken the blow given by the catch pins when the stroke is too long.

*z z*, two friction-wheels, on which the gudgeon or center of the great beam is hung; they are the third or fourth part of a circle, and move a little each way as the beam vibrates. Their use is to diminish the friction of the axis, which, in so heavy a lever, would otherwise be very great.

When this engine is to be set to work, the boiler must be filled about three or four feet deep with water, and a large fire made under it; and when the steam is found to be of a sufficient strength by the puppet-clack, then by thrusting back the spanner, which opens the regulator or steam-cock, the steam is admitted into the cylinder, which raises the piston to the top of the cylinder, and

forces out all the air at the snifting valve; then by turning the key of the injection-cock, a jet of cold water is admitted into the cylinder, which condenses the steam and makes a vacuum; and the atmosphere then pressing upon the piston, forces it down to the lower part of the cylinder, and makes a stroke by raising the column of water at the other end of the beam. After two or three strokes are made in this manner, by a man opening and shutting the cocks to try if they are right, then the pins may be put into the pin-holes in the working-plug, and the engine left to turn the cocks of itself, which it will do with greater exactness than any man can do.

Many important improvements have been lately made in the steam engine by the ingenious Mr. Watt, of Birmingham. He has contrived to preserve an uniform heat in the cylinder of his engines, by suffering no cold water to touch it, and by protecting it from the air, or other cold bodies, by a surrounding case filled with steam, or with hot air or water, and by coating it over with substances that transmit heat slowly. He makes his vacuum to approach nearly to that of the barometer, by condensing the steam in a separate vessel, called the condenser, which may be cooled at pleasure without cooling the cylinder, either by an injection of cold water, or by surrounding the condenser with it, and generally by both. He extracts the injection water and detached air from the cylinder or condenser by pumps, which are wrought by the engine itself, or blows them out by the steam. As the

entrance

entrance of air into the cylinder would ſtop the operation of the engines, and as it is hardly to be expected that ſuch enormous piſtons as thoſe of ſteam engines can move up and down, and yet be abſolutely tight in the common engines, a ſtream of water is kept always running upon the piſton, which prevents the entry of the air; but this mode of ſecuring the piſton, though not hurtful in the common ones, would be highly prejudicial to the new engines. Their piſton is therefore made more accurately; and the outer cylinder, having a lid, covers it, the ſteam is introduced above the piſton; and when a vacuum is produced under it, acts upon it by its elaſticity, as the atmoſphere does upon common engines by its gravity. This way of working effectually excludes the air from the inner cylinder, and gives the advantage of adding to the power, by increaſing the elaſticity of the ſteam.

In Mr. Watt's engines, the cylinder, the great beams, the pumps, &c. ſtand in their uſual poſitions. The cylinder is ſmaller than uſual, in proportion to the load, and is very accurately bored.

In the moſt complete engines, it is ſurrounded, at a ſmall diſtance, with another cylinder, furniſhed with a bottom and a lid. The interſtice between the cylinders communicates with the boilers by a large pipe, open at both ends, ſo that it is always filled with ſteam, and thereby maintains the inner cylinder always of the ſame heat with the ſteam, and prevents any condenſation within it, which would

would be more detrimental than an equal condenſation in the outer one. The inner cylinder has a bottom and piſton as uſual; and as it does not reach up quite to the lid of the outer cylinder, the ſteam in the interſtice has always free acceſs to the upper ſide of the piſton. The lid of the outer cylinder has a hole in its middle; and the piſton rod, which is truly cylindrical, moves up and down through that hole, which is kept ſteam-*tight* by a collar of oakum ſcrewed down upon it. At the bottom of the inner cylinder, there are two regulating valves, one of which admits the ſteam to paſs from the interſtice into the inner cylinder below the piſton, or ſhuts it out at pleaſure; the other opens or ſhuts the end of a pipe, which leads to the condenſer. The condenſer conſiſts of one or more pumps furniſhed with clacks and buckets (nearly the ſame as in common pumps) which are wrought by chains faſtened to the great working beam of the engine. The pipe, which comes from the cylinder, is joined to the bottom of theſe pumps, and the whole condenſer ſtands immerſed in a ciſtern of cold water ſupplied by the engine. The place of this ciſtern is either within the houſe or under the floor, between the cylinder and the lever wall; or without the houſe between that wall and the engine ſhaft, as conveniency may require. The condenſer being exhauſted of air by blowing, and both the cylinders being filled with ſteam, the regulating valve which admits the ſteam into the inner cylinder is ſhut, and the other regulator which communicates with the condenſer is opened,

and

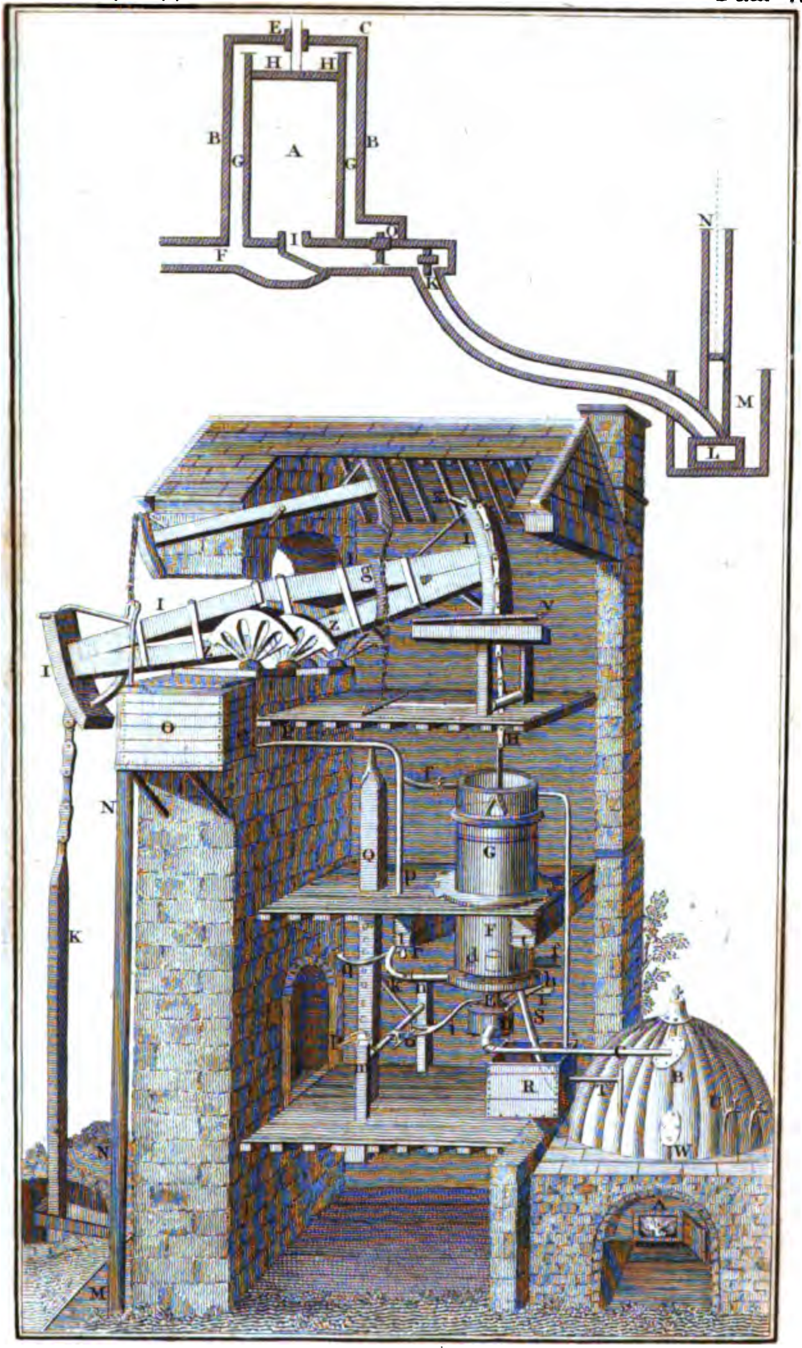
and the ſteam ruſhes into the vacuum of the condenſer with violence; but there it comes into contact with the cold ſides of the pumps and pipes, and meets a jet of cold water, which was opened at the ſame time with the exhauſtion regulator; theſe inſtantly deprive it of its heat, and reduce it to water; and the vacuum remaining perfect, more ſteam continues to ruſh in, and be condenſed until the inner cylinder is exhauſted. Then the ſteam which is above the piſton, ceaſing to be counteracted by that which was below it, acts upon the piſton with its whole elaſticity, and forces it to deſcend to the bottom of the cylinder, and ſo raiſes the buckets of the pumps which are hung to the other end of the beam. The exhauſtion regulator is now ſhut, and the ſteam one opened again, which, by letting in the ſteam, allows the piſton to be pulled up by the ſuperior weight of the pump rods; and ſo the engine is ready for another ſtroke.

But the nature of Mr. Watt's improvement will be perhaps better underſtood from the following deſcription of it, as referred to a figure.—The cylinder or ſteam veſſel A, of this engine (fig. 2.) is ſhut at bottom and opened at top as uſual, and is included in an outer cylinder or caſe BB, of wood or metal, covered with materials which tranſmit heat ſlowly. This caſe is at a ſmall diſtance from the cylinder, and cloſe at both ends. The cover C has a hole in it, through which the piſton rod E ſlides; and near the bottom is another hole F, by which the ſteam from the boiler has always free entrance into this caſe

case or outer cylinder, and by the interstice GG between the two cylinders has access to the upper side of the piston HH. To the bottom of the inner cylinder A is joined a pipe I, with a cock or valve K, which is opened and shut when necessary, and forms a passage to another vessel L called a *condenser*, made of thin metal. This vessel is immersed in a cistern M full of cold water, and it is contrived so as to expose a very great surface *externally* to the water, and internally to the steam. It is also made air-tight, and has pumps N wrought by the engine, which keep it always exhausted of air and water.

Both the cylinders A and BB being filled with steam, the passage K is opened from the inner one to the condenser L, into which the steam *violently* rushes by its elasticity, because that vessel is exhausted; but as soon as it enters it, coming into contact with the cold matter of the condenser, it is reduced to water, and the vacuum still remaining, the steam continues to rush in till the inner cylinder A below the piston is left empty. The steam which is above the piston, ceasing to be counteracted by that which is below it, acts upon the piston HH, and forces it to descend to the bottom of the cylinder, and so raises the bucket of the pump by means of the lever. The passage K between the inner cylinder and the condenser is then shut, and another passage O is opened, which permits the steam to pass from the outer cylinder, or from the boiler into the inner cylinder under the piston; and then the superior weight of the bucket and pump rods

pulls


E
C
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L

pulls down the outer end of the lever or great beam, and raises the piston, which is suspended to the inner end of the same beam.

When water is exposed to a cold atmosphere, it first loses its free caloric, and is reduced in temperature, but no part of it begins to freeze till the mass is reduced somewhat below the thirty-second degree of Fahrenheit's thermometer; a small quantity of the water then becomes solid, which, by changing its state, sets at liberty a quantity of its combined heat, which restores the water in contact with it to the temperature of 32 degrees, or rather above it. The congelation is therefore at a stand till this sensible heat is abstracted by the atmosphere, and the mass again reduced somewhat below the thirty-second degree. Another portion of water then congeals, and the process is again stopped by the emission of heat. In this manner congelation pervades the whole mass, and is performed at intervals, which are very observable when the phenomenon of freezing is accurately attended to.

The same law operates in the passage of other bodies from the state of fluids to that of solids, and the contrary. Dr. Irvine has shewn, that when spermaceti and wax are melted, they contain heat in a combined or latent state. By heating them much above their point of fluidity, he found that they lost their heat very soon, till some parts became solid; after this they continued of exactly the same temperature till the whole became solid, though exposed all the while to cold air; but when all became solid they cooled as they did at first. In the same manner

manner water mixed with ice, whatever may be the temperature of the surrounding medium, and whether the quantity of ice is increasing or diminishing, always nearly preserves the temperature of 32 degrees.

The freezing of water was formerly attributed to the entrance of frigorific particles into that fluid; but the above doctrine, founded on the great discoveries of Dr. Black, is almost universally deemed so satisfactory as to have left the other, which is a mere hypothesis, scarcely a single advocate. The augmentation of the bulk of water in freezing seems to be the only fact which can with reason be alledged in support of the doctrine of frigorific particles; but this increase of bulk is not attended with any increase of weight, and may be much better explained, than by attributing it to the addition of frigorific particles, which were never proved to have any existence.

The increase which water acquires in becoming solid is about one-ninth or one-tenth of its whole bulk: Boyle took a brass tube, three inches in diameter, and put some water into it; he then brought down into the tube a plug with a weight placed at the head of it of seventy-four pounds. On exposing the tube to the cold, the water freezing and expanding itself, raised the seventy-four pounds. The expansive power of water, in the process of freezing, was proved by a remarkable experiment made in Canada. An iron shell, after having its mouth well plugged up, was filled up with water and exposed to a severe frost which prevailed in that

country. The expansion of the ice forced out the plug, and the water, which immediately followed, was frozen into an irregular mass or column of ice. The instances, however, already mentioned, are far less striking than one described by Muschenbroeck, in which a ball of iron, an inch thick, was burst asunder in the course of twelve hours by the expansive power of frost. That philosopher having calculated the force exerted by the freezing of water in a similar case, found it equal to a force capable of raising a weight of twenty-seven thousand seven hundred and twenty pounds. That the expansive power of freezing water, however, has certain limits, appears from the following experiment, made by the Florentine academicians. A brass globe filled with water, and closed at its orifice by a well-fitted screw, was immersed in freezing water, but did not burst; they then pared off such a quantity of the metal as left the sides of the globe unable to resist the expansion of the water; the force which was required to burst the globe in this state was computed at twenty-seven thousand pounds. When such is the expansive power exerted by water in passing to the state of ice, we cannot be surprized that vessels, which are left filled with water in frosty weather, should be burst by its freezing, and that the same thing should happen to water-pipes exposed to the action of frost. The pavement is sometimes loosened from the same cause, and in countries where very severe colds prevail, the sap of trees congeals, and their trunks are burst asunder with a noise like that of cannon.

Frost

Froſt fertilizes the ground, by looſening the coheſion of the particles of earth.

As ice is never perfectly clear or tranſparent, and as we find ſmall cavities in it, ſome have thought that the air inſinuates itſelf; but this has been refuted by water being frozen under an exhauſted receiver, and the ſame cavities being found in the ice. The ice, in fact, inſtead of being heavier, was found to be lighter. The expanſion of ice, indeed, is evidently owing to the cryſtallization of the water, and the particles aſſuming a different arrangement, and not being in cloſe contact. If this is admitted, as I apprehend it muſt, we cannot ſay, with propriety, that the ſolid particles of water expand. The ſpiculæ, of which ice conſiſts, cut each other at angles of ſixty or one hundred and twenty degrees.

When it ſnows at Moſcow, and the air is not too dry, it is obſerved to be loaded with beautiful cryſtallizations, regularly flattened, and as thin as a leaf of paper. They conſiſt of an union of fibres, which ſhoot from the center to form ſix principal rays, which are themſelves divided into extremely ſmall blades.

It appears, however, that the air previouſly contained in water is ſet at liberty on the congelation of that fluid, and may thus partly contribute to the ſwelling of ice, and occaſion ſome of the cavities obſervable in it.

When water freezes ſlowly, its ſurface preſerves its tranſparency to ſome depth, owing to the air which is ſeparated paſſing downwards as the freezing proceeds. The air bubbles, however, ſoon begin to collect,

collect, and produce considerable inequalities, which increase as they approach the center. When, on the contrary, water is frozen with great rapidity, the bubbles of air disperse themselves pretty equally through the mass, which, in consequence, becomes opake through its whole substance.

Reaumur observes that cast iron melted, in passing from a fluid to its solid state, expands. This effect is more sensible in this than in any other of the metals, on account of its platey texture. He found that cast iron, thrown among some of the same metal melted, swims upon the top. In the case of immediate expansion upon congealing, the iron seems to agree with water: they differ in this; the iron never expands by cold afterwards, whereas the ice, being exposed to greater degrees of cold, becomes more bulky; the solid parts not being so closely connected from a particular arrangement, which renders the whole mass lighter than before. Quicksilver contracts in becoming solid; and both cast iron and ice contain several interstices, which, if allowed for, make it appear that these bodies in reality occupy less space when solid, than in a fluid state.

# Chap. II.

## HYDROSTATICS.

*Discoveries of Archimedes in this Branch of Science.—Of the Moderns.—How Fluids are acted upon by the general Laws of Gravitation.—Particles of Fluids act independently of each other.—Experiment ascertaining this Principle.—Fluids press equally in all Directions.—Cautions necessary in constructing Aqueducts, &c. to guard against the lateral Pressure of Fluids.—All Parts of the same Fluid in Equilibrium with each other.—Surfaces of Fluids always in a Plane parallel with the Horizon.—Pressure of Fluids in proportion to their Height.—Hydrostatic Paradox.—Effects of Gravity on Fluids of different Densities.—Action of Air on the Surfaces of Fluids.—The Siphon.—Action of Fluids on solid Bodies immersed in them.—Why certain Bodies sink and others swim in certain Fluids.—Bodies that swim displace a Bulk of Water equal to themselves in Weight but not in Magnitude.—The same Body will sink in one Fluid, which will swim in another.—The Hydrometer.—Fahrenheit's Hydrometer.—Recapitulation of the Doctrines respecting specific Gravity.—How to make a Globe of Iron swim on the Surface of Water.—Boats made of Copper.*

WATER, as a fluid, has certain properties, which, though common to all unelastic or incompressible fluids, are usually considered under this topic; and indeed the sciences of hydrostatics and hydraulics, which regard these properties, immediately derive their names from that fluid *, on

* Ὕδωρ (Hydor) water, and στατικη (statiké) the science of weight. Hydraulics from ὕδωρ and αυλος (aulos) a tube or pipe.

which

which the experiments, illustrative of them, are usually made.

Hydrostatics have for their object the weight and pressure of fluids; and in this branch of science the art of determining the specific gravities of bodies is usually included, but this I have already been under a necessity of anticipating * in some degree. *Archimedes*, among the ancients, accomplished the most remarkable discoveries in this science. He is honoured even at this day, as the inventer of the ingenious hydrostatic process, by which the purity or baseness of a crown of gold was ascertained. Among the moderns we are indebted to Gallileo, Torricelli, Descartes, Pascal, Guglielmini, and Mariotte, for the best information on this subject; and by their experiments (which are as curious as they are decisive) we are instructed in what we may expect or fear from the power of fluids violently acted upon by the principle of gravity, and in what manner and upon what principles we may employ, for the use of man, the hydraulic machines.

It has been observed in another place, that the propensity which bodies have of approaching towards the earth, or perhaps towards its center, is the only cause of what we term weight, or gravity, and that it is by the continual efforts which they

* See Book I. Chap. III. It was necessary to explain the nature of specific gravity in that part of the work, both because it relates rather to bodies in general than to fluid substances; and because the frequent allusions to it in the progress of the work would not have been otherwise understood.

make to obey that law, that they press upon every obstacle which impedes their progress. As fluids, like solid bodies, are impelled by their gravity, so in this case they press upon every object which opposes their fall; but from their nature they press in a different manner from solid bodies; hence arise the peculiar phenomena into which we are now to inquire.

Fluids are substances, the component parts of which are moveable among themselves, having scarcely any cohesion one with another, and moving independently of each other. Some philosophers * have included in this definition what they term the grosser fluids, as, for example, a heap of corn, a heap of shot, of sand, &c. as well as the rarer and more elastic fluids, as common air, and all other aeriform substances. The proper objects, however, of the hydrostatic science, are those fluids which, in common language, are termed liquids, or those which always present to us a plane surface, level or parallel to the horizon.

All liquid substances are not equally so; hence it follows, that the laws of hydrostatics apply with less exactness in proportion as those substances depart from perfect fluidity. Water and oil both flow when the vessels, which contain them, are either overturned or broken; but the effusion of oil is slower than that of water, because the particles of oil have more cohesion among themselves. The most singular effects in hydrostatics princi-

* See Brisson, Vol. I. p. 233.

pally

pally depend upon the extreme minuteneſs of the particles of fluids, and upon their great mobility.

To preſerve a lucid order in the conſideration of this ſubject, it will be neceſſary to divide the objects of our inquiry into three branches. In the firſt place, therefore, I ſhall conſider in what manner the principle of gravity acts on the particles of fluids, and the phenomena which it produces in the fluids themſelves; as well as their action againſt the ſides, the bottoms, and tops of the veſſels in which they are contained. Secondly, I ſhall conſider in what manner fluids of different denſities act upon each other; and thirdly, the action of fluids on bodies immerſed in them.

I. In purſuing the firſt object of this inquiry, it may be eſtabliſhed as an axiom:

1ſt, That the parts of the ſame fluid act with reſpect to their weight or preſſure, independently of each other.

This property ariſes from their having ſcarcely any cohesion among themſelves. It is otherwiſe with ſolid bodies; their ſeveral parts adhering together, they preſs in one common maſs; hence the falling of ſolid bodies is productive of a different effect from that of liquids. We dread the falling of a pound of ice upon our heads, while we are much more indifferent concerning that of a pound of water. The latter, in its deſcent, is divided by the reſiſtance of the air, by which ſome of its parts are retarded more than others; and the ſwiftneſs of the whole maſs is ſtill more retarded by this diviſion than it otherwiſe would be; for by

being thus divided it acquires a larger surface, which abates its effect. On the contrary, a solid body falls upon a small space, which receives its whole force. Hence it follows, that angular bodies falling upon any part of the human frame are more dangerous than flat or plane ones of the same weight, and descending from the same height.

It follows from this principle, that if an aperture is made at the bottom of a vessel full of any fluid, in order to prevent the flowing out of the liquor, it is only necessary to counteract the weight of that column of fluid which has the aperture for its base, and that to counteract that weight it is the same whether the vessel is full of liquor, or whether it contains only a column, the base of which shall be equal to the aperture at the bottom.

Let the cylindrical vessel of glass A B (plate V. fig. 1.) have a hole in the bottom at C, furnished with a cylindrical ferule of copper of an inch diameter D, which is to be stopped with a piston G, or the sucker of a pump well fitted to the ferule, and oiled, that it may yield to a moderate pressure. Let the piston be supported by a small rod G H, fastened at H to the silk which unites with the portion of the pulley M, with which the extremity of the lever M N is furnished, and which has for its center of motion the point L. The other portion of the pulley N, which terminates the other extremity of the lever, is also furnished with lines of silk, which support the small bason or scale I. Upon the copper ferule D then fit a cylindrical tube of glass F E, the interior diameter of which

is equal to that of the ferule, and its height equal to that of the vessel A B. When the apparatus is disposed in this manner, fill the tube E F with water, and continue to put small weights into the bason or scale I, until the piston begins to rise. Afterwards take away the glass tube E F, and place the piston G in the copper ferule D, and pour water into the large vessel A B, and it will appear that the same weights as before in the bason I, will raise up the piston when the larger vessel A B is entirely full. Hence it follows that there is the same power to be counteracted, whether there rests upon the piston only a column of water of its own size, or whether the vessel A B is entirely full. Such a column, therefore, presses upon its base independently of the rest of the water contained in the vessel.

To account for this, let us suppose all the water in a vessel to be divided into several columns, 1, 2, 3, 4, 5, (plate V. fig. 2.) each composed of an equal number of parts. If the bottom of the vessel, which serves for the base and support of all the columns, is opened in *a*, the column 3, being no longer supported, will descend through the aperture, sliding between the two columns 2 and 4, which are supported by the parts of the bottom of the vessel *b* and *c*, all the moveable parts of which become (if I may use the expression) small rollers, which retard the fall only in a very slight degree. This effect is the result of the small degree of cohesion between the parts of the fluid. If the columns 1 and 2 on the one part, and 4 and 5 on the

other, were composed of parts adhering together, they would retard each other in their descent during their whole length, in the same manner as a wax candle would do; and by the fall of the column 3, a void would be made between them. But as all the particles are extremely minute, moving easily upon each other, they descend when the summit of the column 3 begins to descend, having no longer any support from that side; and the superficies of the whole mass descends in the same manner, though only one of the columns caused the flow from its fall. When the parts have a degree of viscosity, as those of oily fluids, or when the mass of the flowing liquor has much more of breadth than of height, the void which the descending column leaves above it is easily perceived, for then the surface, instead of being plane and even, is hollow in the middle, and assumes a funnel-like form, because the adjacent parts do not arrive with sufficient swiftness to replace those which descend through the aperture; besides the pressure of the air above the aperture is stronger than its resistance below.

From what has been now stated, it is easy to perceive how fluids differ from solids in the phenomena of gravitation. If the vessel A B (plate V. fig. 1.) being full of water, and the tube E F being removed, it was required to raise up the piston G; all that is necessary in this case is, to support the weight of the column of water directly above the piston, because this column can move independently of the remainder; but if the whole mass of water was converted into ice, then the mass ceasing to

be

be a liquid, and all its parts adhering together, to raise up the piston it would be necessary to support the weight of the whole mass.

2dly, Fluids press equally in all directions.

In other words, they not only press from the top to the bottom like other bodies, but they also press, according to their weight, upon all bodies that oppose them in a lateral direction, and even from the bottom to the top. Hence, if a cask is filled with liquid oil, the oil will run out if an aperture is made in the side, but when it is congealed it will not run out, on account of its having become a solid body, for solid bodies press only from their vertex to their base, and not laterally.

To understand properly this lateral pressure of fluids, and also that which they exert from their base towards their vertex, it is necessary to consider them as a mass of small globules deposited in a vessel; and to remember that these minute globules are not arranged regularly as upon a cord, but that very frequently one column exercises its pressure between two others, and has a propensity to displace them, as may be seen in plate V. (fig. 3.) where the perpendicular pressure which is made opposite to the point *d*, is directed by the lateral columns towards the sides, *e f*, of the vessel, in such a manner, that if the vessel was open in those places the liquid would flow out, on account of the great mobility of its parts. It is by the same mode of reasoning that the pressure of fluids, from their base towards their vertex, is accounted for: for example, when the column *d f* (fig. 3.) has a tendency

dency to displace the two particles *g h*, the particle *g* cannot move any farther because it is impeded by the side of the vessel; but the particle *h* may be raised from the base towards the top, unless a column equal to the column *i k*, or something equivalent, presses upon it to prevent it.

It is upon this principle that the water, elevated by the New River water-works, after having descended from a bason in a vertical pipe, and then after having flowed horizontally in a succession of pipes under the pavement, is raised up again, through another pipe, as high as the fountain at the Temple Garden. It is also upon this principle that a vessel may be filled either at the mouth or at the bottom indifferently, provided that it is done through a pipe, the top of which is as high as the top of the vessel to be filled. Hence it follows, that when piers, aqueducts, reservoirs, or other hydraulic works for the retention of water are to be constructed, it becomes necessary to proportion their strength to the lateral pressure which they are likely to sustain, which becomes greater as the height of the water is more considerable. Nearly the same precautions are necessary to be taken with respect to what some philosophers call the grosser fluids, which also have a propensity to expand, as well on account of the smallness of their parts as from the small degree of cohesion which exists between them. Walls designed to support terrasses ought to be sufficiently strong to resist the lateral pressure of the earth and rubbish which they are to sustain, as this pressure will be greater as the particles of earth,

earth, and of the other materials of which the terrasses are composed, are less bound together, and in proportion as the terrasses are more elevated.

3dly, All the parts of the same fluid are in equilibrium with each other, whether they are contained in one vessel or many, provided they communicate with each other; and their surfaces also are always in a plane parallel to the horizon.

This is a consequence of the principle which has been before established: for, since the particle *b* (fig. 3.) would be raised from the base towards the top, unless a column equal to the column *i k*, pressed upon it to retain it in its place; it follows that to be in equilibrium, the upper extremities of the two columns should be in the same horizontal plane, or in points equally distant from the center of the earth; which points, however, cannot be found by a right line; for in the distance of a thousand fathoms there is about one foot difference in the perpendicular height. From this property of fluids it follows, that water conducted by pipes placed in the earth, will remount as high as the place whence it flowed, whatever the depth under ground through which it may have been conducted by pipes. It is customary to allow half an inch of inclination in the length of six feet, to counteract the resistance produced by friction; but it is clear, from what has been said, that this is not absolutely necessary, for however long the passage might be, the water would still ascend as high as the place whence it came, but it would require a little longer time to accomplish the ascent. We

are

are enabled, upon this principle, to account for the ſprings which are ſometimes found on the tops of mountains. Such waters flow from mountains ſtill more elevated (whether they are far or near) by ſubterraneous canals. It follows from this principle, that if there are many reſervoirs which communicate together, it is neceſſary only to ſee one of them to know the height of the water in the others; for it muſt neceſſarily be of the ſame height there as in all the reſt.

From what has been obſerved, viz. that when all the parts of the ſame fluid are in equilibrium, their ſurfaces will alſo be in a plane parallel to the horizon, or, in other words, every part of the ſurface at an equal diſtance from the center of the earth, it follows, that when the ſurface of water is very large, it becomes neceſſarily and ſenſibly convex. This is eaſily perceived at ſea, where the maſts of ſhips are obſerved at a diſtance before any other part of the ſhip can be diſtinguiſhed.

4thly, Fluids preſs as well perpendicularly as laterally, not, however, in proportion to their quantity, but in proportion to their height above the plane of the horizon.

For example, if ſeveral veſſels of the ſame height and baſe are filled with water, all their bottoms will bear the ſame degree of preſſure, whatever may be the form and ſize of the veſſels in other reſpects. Suppoſe three veſſels to be filled with water, ABCD (fig. 4.) EFGH (fig. 5.) LMNO PQ (fig. 6.) whoſe heights AB, IF, LT are equal, and alſo ſupported by equal baſes BC, FG,

NO;

N O; it will be found, by experiment, that all the bottoms of these vessels will be equally pressed, though the quantities of water which they contain may be very different. In the vessel (fig. 4.) the bottom B C is pressed by the whole mass of water A B C D, because the fluid, in this case, presses in the same manner as a solid body; let us suppose the weight of the water to be six pounds: In the vessel (fig. 5.) it is easy to conceive, from what has been said before, that the bottom F G is also only pressed by six pounds, though the vessel is evidently much larger than the first; because the bottom F G supports only the column I F G K, equal to that of the vessel (fig. 4.) and this column exercises its pressure independently of the residue of the water in the vessel, which is supported by the sides, E F, H G, of the vessel (fig. 5.) But the principal difficulty consists in comprehending how the bottom of the vessel N O is still pressed by a weight of six pounds, although one pound of water would be sufficient to fill the vessel. It is accounted for in this manner; it is certain that upon the portion T V of the bottom N O, there is a pressure equal to that of a column of water of which T V is the base, and L T the height. If, upon every other similar portion of the same bottom, there is a pressure equal to that of the column L T V Q, the bottom is equally pressed upon all its parts. For instance, there is a pressure upon the portion V X equal to that of a column of water Q V X R, which is itself equal to the column L T V Q; for the small column of water P V X S, which rests above,

above, has a propensity to be elevated by the pressure of the adjacent column L T V Q, and with a force equal to the excess L M P Q of this great column over the small one; therefore the upper part, P S, is pressed by the same power; but the re-action is equal to the pressure. The part P S re-acts with a force equal to the excess L M P Q of the great column over the small one. There is, therefore, a pressure upon the portion V X of the bottom N O, from the small column of water P V X S, and from the re-action of the part P S, equal to the pressure of a column of water, Q P S R, both of which added together are equal to the pressure of the column L T V Q. What has been said of the portion V X may be said of all the rest. Hence it follows that the bottom of the vessel (fig. 6.) is every where equally pressed.

There is a maxim deduced from what has been stated, which is termed by philosophers the hydrostatic paradox; it is nevertheless founded upon the surest basis of truth, and has a considerable influence in almost all hydraulic engines, viz. "that a given quantity of water may exert a force two or three hundred times less or greater, according to the manner in which it is employed." If, for instance, the same quantity of water as the vessel (fig. 5.) will contain, is poured into a vessel resembling that of (fig. 6.) but high enough to contain it, the pressure upon the bottom N O will be considerably greater than that upon the bottom F G.

One of the most useful machines to shew that a small quantity of water is capable of great pressure, is

Fig. 1.

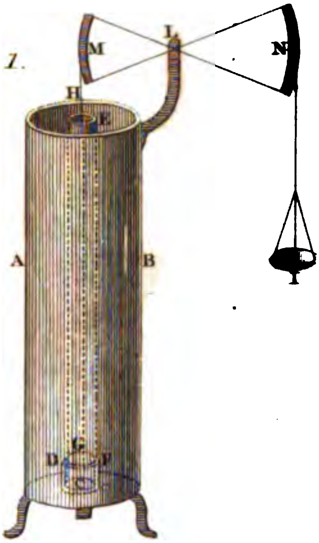



Fig. 2.


Fig. 3.

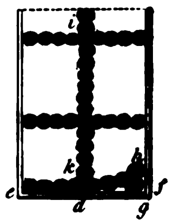



Fig. 4.


Fig. 5.

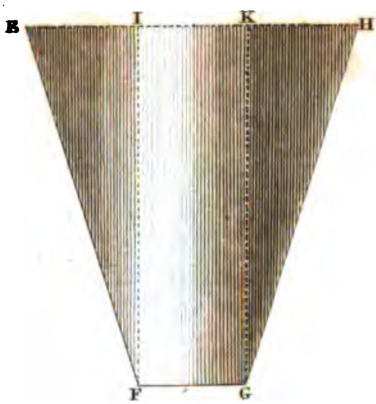
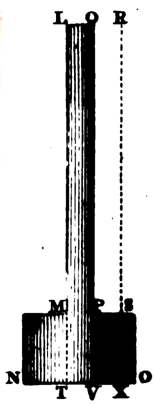



Fig. 6.



is the hydroftatic bellows. This machine (Plate VI. fig. 1.) confifts of two thick oval boards, each about three feet broad, and four feet long, united to each other by leather, like a pair of common bellows, or a barber's puff. Into the lower board a pipe B, feveral feet high is fixed at *e*. Now, in fhewing experiments with this fimple machine, which even the reader himfelf might eafily make, let water be poured into the pipe at its top C, which will run into the bellows, and feparate the boards a little: then to fhew how much a little water will be able to effect by preffure, let three weights, each of an hundred pounds, be laid upon the upper board. Now if we pour more water into the pipe, it will as before run into the bellows, and raife up the board with all the weights upon it. And though the water in the tube fhould weigh in all but a fingle pound, yet the preffure of this fmall force upon the water below in the bellows, fhall fupport the weights, which are three hundred pounds; nor will they have weight enough to make them defcend, and conquer the weight of the water, by forcing it out of the mouth of the pipe.

It is clear from thefe principles, that the tun TO (fig. 2.) filled with water, may be burft by preffing it with fome pounds additional weight of the fluid, through the tube A B, which may be fuppofed to be from twenty-five to thirty feet in height. From what has been faid of the veffel (fig. 6.) it indeed neceffarily follows, that the fmall quantity of water which the tube A B contains, preffes upon the bottom of the tun as much as if a

column

column of water had been added as wide as the tun itself, and as long as the tube, which would evidently be an enormous weight.

II. The effects of gravity on fluids of different densities will, from what has preceded, not be very difficult to comprehend.

It has been observed, that fluids are masses of small bodies moveable with great facility among themselves independently of each other, pressing separately and in proportion to their masses.

It is proved also by chemical analysis, that even these minute particles are composed of particles still smaller. Now whether it results from the interposition of caloric (or the matter of fire) in greater or less quantities, which we know is the cause of all fluidity, and also of the difference that exists between the incompressible and elastic fluids; or whether it may depend upon the shape or size of the particles, which, as in solid bodies, may increase or diminish the porosity, it is certain, that there is a considerable difference with respect to density in different fluids.

From this difference in point of density, a separation may be observed generally to take place, soon after mixing two heterogeneous fluids together, unless this effect is counteracted by some more powerful cause. It has been observed, that the particles, according to their weight, press independently of each other. Those therefore which have the most density, having more power to gain possession of the lower part of the vessel which contains them, oblige the others to yield and resign their

their situation; and hence a separation is effected. When oil and water, for instance, have been well shaken together, and afterwards the whole left in a state of rest, the water, having more density than the oil, takes the lower position and the oil rises to the surface. If this effect does not take place, it is owing to the intervention of one of the following causes. First, a kind of elective attraction, which may exist between the particles of different fluids, as when water and wine are mixed together, the water, though heavier than the wine, does not separate itself. Secondly, the viscosity of one of the substances, as when the whites of eggs are beaten together, and by that means a considerable quantity of air mixes with them; the air, though much lighter, has not power to disengage itself from the matter in which it is enveloped, in order to effect its escape.

If two fluids of different densities are placed in a state of equipoise with each other, and have the same base, their perpendicular heights above the horizon will be in a reciprocal ratio to their densities or specific gravities.

If, for example, mercury is put into an inverted siphon, and water is poured into one of the branches, in order to elevate the mercury in the other branch one inch above its level, it is necessary that the water should be about thirteen inches and an half high. The height of the water then will be thirteen times and a half of that of the mercury; because the specific gravity of mercury is about

thirteen times and a half as great as that of water.

This obſervation will alſo apply to the reciprocal action of air and water, or air and mercury upon each other, as was evinced in a former book, when treating of the Torricellian experiment and the barometer *. Many of the phenomena, indeed, of hydroſtatics and hydraulics are to be referred to the preſſure of the atmoſphere, and for this reaſon, the preſent ſubject has been in part anticipated, when it was neceſſary to treat of air as a fluid.

It is, however, proper on the preſent occaſion, to recal to the reader's attention ſome of the properties of this fluid, and he will eaſily remember, that as a fluid, air is poſſeſſed of gravity, and conſequently preſſes upon all bodies which oppoſe it; and it is neceſſary to add, that like water, it preſſes in all directions. Its perpendicular preſſure has been already ſufficiently proved; and its lateral preſſure may alſo be eaſily demonſtrated. If a ſmall hole is made with a gimblet, either in the ſide or bottom of a caſk or veſſel which is quite full of liquor, it will not run out, becauſe the external air which preſſes againſt the hole, ſuſtains the liquor, which has not a ſufficient height to overcome its preſſure. Hence the neceſſity of a vent-peg, to enable liquor to be drawn out of a full caſk. The elaſticity of the ſmall quantity of air which is introduced at the vent preſſes the fluid, and overcomes the preſſure of the air at the cock. There is an

* See Book v. Chap. 9.

instrument in common use, called a Valencia, for extracting small quantities of liquor out of the bung-holes of casks. It is a tube with a small aperture at the bottom and the top. When full, if the hole at the top is stopped with the thumb or finger, so as to prevent the pressure of the air at the top, the liquor will not run out of the hole at the bottom; being kept in by the force of the external air.

It is proper to observe, that all the effects which depend upon the pressure of air, take place in a room where the column of air is terminated by the ceiling, as well as without doors where the column of air has the whole height of the atmosphere; and the reason is, because the air in the room has a communication with that on the outside, supposing it to be only by means of the key-hole. Thus a barometer placed in a hall, will have its mercury as high as if it was placed in an open field.

The curious effects produced by siphons, all depend upon the pressure of the air.

A siphon is a bent tube A B C (fig. 3), made of glass, of metal, or of wood. One branch of which A B, is shorter than the other B C. In order to make use of this instrument, place the extremity of the short branch A B in the vessel E E; (fig. 4.) which may be supposed to contain any fluid matter, as water for instance. If the air then is drawn by suction* out of the siphon at the extremity C of the long

* Suction is here evidently used in the popular sense of the word, to imply that action of the mouth which extracts the air from a given space: for in strict philosophical language there is no such thing.

branch B C, the liquor will begin to flow, and will not ceaſe while the ſhort branch A B remains immerſed in the fluid. It is eaſy to ſee that the preſſure of the air upon the ſurface of the fluid in the veſſel, is the cauſe of its diſcharge through the ſiphon. For ſuppoſe G F the confines of the atmoſphere, all the points of the ſurface A of the liquor will be equally preſſed by the column of air A F; if, therefore, at ſome point of this ſurface, the preſſure is ſuſpended, the liquor muſt flow at that point, becauſe it finds leſs reſiſtance there than in any other part; this is therefore the obvious reaſon why the ſiphon becomes full immediately after the air is drawn out at the extremity C.

If the two branches of the ſiphon were of equal lengths, as B A, B D, the flow through the bent tube would not take place; becauſe the column of air D G which would reſiſt in D, being of an equal height with that which preſſes at A, would alſo be in equilibrium with it, in the ſame manner as the two columns of the fluid B A, B D. But ſince B C, one of the legs, is longer than the other, though the column of air G C, which anſwers to it, is really longer than that which preſſes in A; yet it is not capable of preventing the paſſage of the fluid. To underſtand this more perfectly, let us conſider the column of air G C to be divided into two parts, one of which, G D, would form an equipoiſe with the column of air F A, and would be capable of ſtopping the flow from the tube if the branch B C ended in D. The portion of fluid which fills the part D C of the ſiphon, will find no other reſiſtance in

C than

C than one column of air D C of the same length with it, which is evidently very inferior to it in weight. This portion of fluid then flows out, because it greatly exceeds in weight the column of air which is opposed to it. But while it continues to flow, nothing sustains that which is above it, which flows necessarily, while the pressure of the air at A furnishes a new supply of fluid to replace that which runs out. It is by these means, that the water in the siphon continues to flow without intermission; because the resistance of the air in C is as much exceeded, as the length of the branch B C of the siphon exceeds that of the branch A B. In order to prove this, suppose there is added at C a tube to lengthen that branch, then it will plainly appear, that in a given time more water will flow than would have been discharged without that augmentation to the branch B C.

Since it is the pressure of the air which elevates the fluid in the short branch B A, it follows, that the height of this branch is limited to thirty-two feet when the fluid is water, because the pressure of the atmosphere cannot elevate water higher; but when the liquor is mercury, the height of the short branch should not exceed thirty inches, because the atmosphere cannot sustain mercury at a greater height.

III. The action of fluids on solid bodies immersed in them, has been already in part anticipated, in treating of specific gravity. It is necessary, however, to resume that subject to a certain extent

in this place, and I ſhall endeavour as much as poſſible to avoid repetition.

It is evident, that when a ſolid body is plunged into a fluid, it occupies a ſpace in that fluid exactly equal to its own magnitude. The quantity of fluid then ſo diſplaced, either equals in denſity and conſequently in weight, the ſolid which diſplaced it; or, on the contrary, one of the two muſt weigh more than the other. In the laſt caſe, which is moſt common, the quantity by which the heavier body ſurpaſſes the lighter, is called the ſpecific weight or gravity.

It has been obſerved before, that fluids exerciſe their preſſure in all directions, conſequently a ſolid body plunged into a fluid is preſſed at all points. It has alſo been proved, that this preſſure increaſes in proportion to the height of the fluid; the preſſure, therefore, which the body undergoes, is greater in proportion to the depth into which it is plunged. Laſtly, it has been proved, that when two fluids are placed in equipoiſe, their reſpective heights are in proportion to their denſities; and therefore bodies plunged to an equal depth, are compreſſed according to the denſity of the reſpective fluid.

If a body is heavier than the fluid in which it is immerſed, it is evident that it will ſink to the bottom, by its ſpecific gravity. If a body is lighter than the ſame bulk of the fluid into which it is plunged, a part of it will ſwim, and the remaining part which is immerſed diſplaces a quantity of

fluid which weighs exactly as much as the whole of the solid body *.

* 'From what I have already explained, you must necessarily have discovered the rationale of *sinking* and *swimming*. You saw that when a body was bulk for bulk heavier than the fluid, by being immersed it loses only the weight of an equal bulk of the fluid, and consequently the *residual* or remaining gravity of the solid must carry it down to the bottom, or make it *sink*.

On the other hand, if the solid has less weight in the same bulk than the fluid, then it cannot by its weight displace or raise upwards its whole bulk of the fluid, but only so much of it as is equal to its own weight, and from this deficiency in weight it will be only partly immersed, and will therefore *swim* upon the upper part of the fluid.

Of all the animals, however, thrown into the water, man is the most helpless; the brute creation receive the art of swimming from nature, while man can only acquire it by practice; the one escapes without danger, the other sinks to the bottom. Some have asserted, that this arises from the different sensibilities each have of the danger; the brute, unterrified at his situation, struggles, while his very fears sink the lord of the creation.

But much better reasons may be assigned for this impotence of man in water, when compared to other animals; and one is, that he has actually more specific gravity, or contains more matter within the same surface than any other animal. The trunk of the body in other animals is large, and their extremities proportionably small; in man it is the reverse, his extremities are very large in proportion to his trunk. The specific weight of the extremities is proportionably greater than that of the trunk in all animals, and therefore man must have the greatest weight in water, since his extremities are the largest.

Besides this, other animals to swim have only to walk (as it were) forwards upon the water; the motion they give their limbs in swimming is exactly the same they use upon land; but it is different with man, who makes use of those limbs to help him forwards upon water, which he employs to a very different purpose upon land.' ADAMS's *Lectures*, Vol. iii. p. 408.

If, for inſtance, water is poured into a glaſs veſſel (fig. 5.) furniſhed with a ſmall cock near the bottom; if the height of the water in the veſſel is marked with a ſmall bandage of thread or paper; and, laſtly, if a ball of wood is thrown into it, it will appear that part of the wood will be immerſed, and part of it remain above the water, and that the immerſed part will raiſe the water in the veſſel juſt as much as if a volume of water had been added equal to the ſolid contents of the part under water.

If a quantity of water is then let out of the veſſel by means of the ſmall cock, until the ſurface is reduced as low as the mark which pointed out its height at the beginning of the proceſs, it is clear, that the water drawn out in this manner will be equal in its ſolid contents to thoſe of the immerſed part of the wooden ball; and alſo, if this volume of water is weighed, it will be found to be of exactly the ſame weight as the whole ball of wood.

Hence it follows, that a boat upon a river diſplaces a quantity of water exactly of the ſame weight with the boat and its lading; and if more weight is added, it will ſink deeper in the water in the ſame proportion; and the immerſed part is more or leſs in extent, according to the denſity of the water. Hence, as water when impregnated with ſalt, is heavier and denſer than pure water, as was formerly proved*; it follows, that the ſame boat and lading will *draw* leſs water (according to the ſeaman's phraſe) in the ocean, than in a river of

* Book vi. chap. 7.

fresh

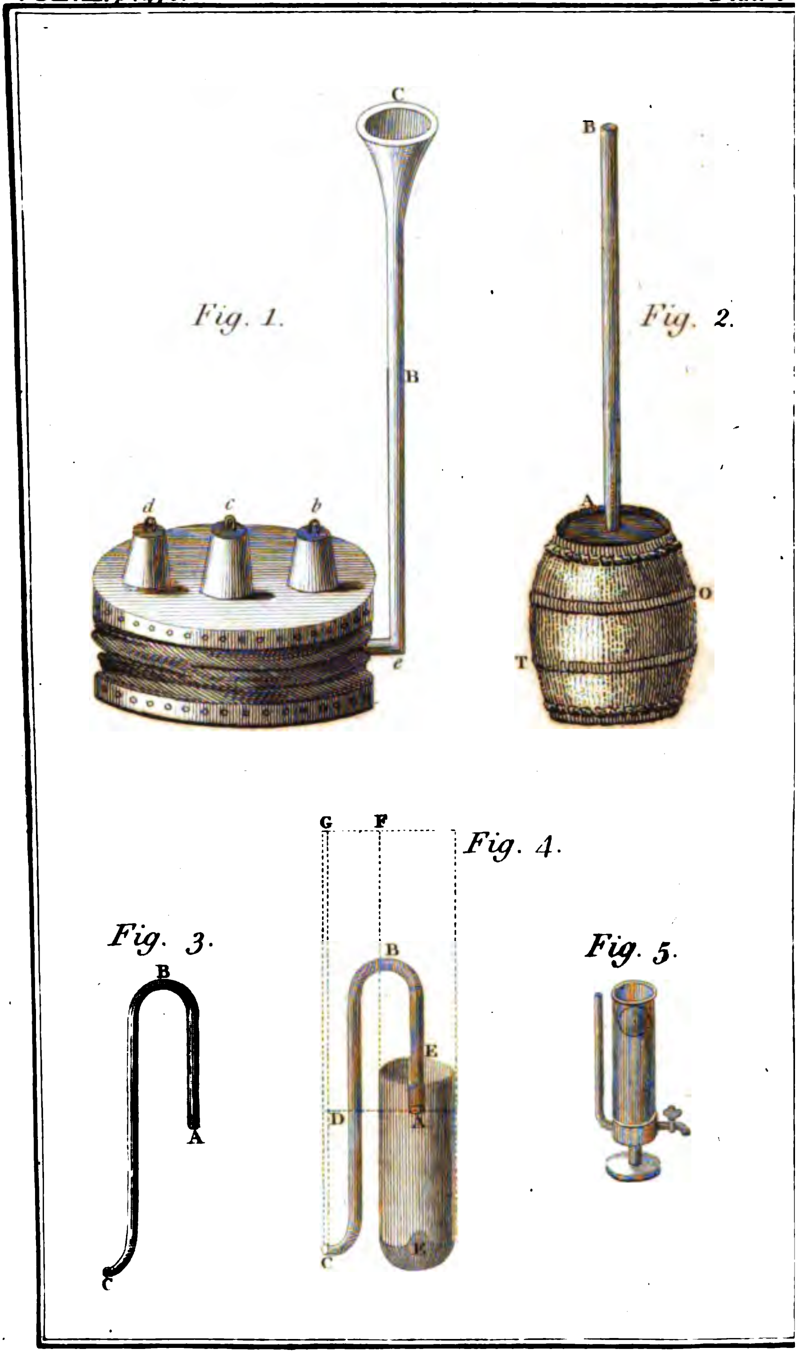


Fig. 1.
C
B
d
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Fig. 2.
B
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O
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Fig. 3.
B
A
C
Fig. 4.
G
F
B
E
D
A
K
C
Fig. 5.

fresh water, and that if it is laden to the utmost extent in salt water, it will sink when it comes into fresh water

Upon this principle depends the use of the hydrometer. For it will be found that bodies immersed in mercury, sustain a greater loss of weight, or require a greater power to sink them, than in salt water; in salt water than in fresh; and in pure water, they still sustain a greater loss of weight than in spirits of wine, which is a lighter and less dense fluid.

The hydrometer, then, is an instrument by which the specific gravity of different fluids is determined. The most simple, and that which is most in use, consists of a glass globe with a long narrow neck (plate VII. fig. 1.) A C, divided all the way up into equal parts. In order that this instrument may sustain itself in the middle of liquors in a vertical position, it is made in such a manner that the center of gravity is in the lower part of it; it is for this purpose, that another small hollow ball S is placed under the larger ball, in which some mercury is usually lodged, but in such a quantity only as that the whole hydrometer shall weigh about as much as an equal bulk of that fluid which is appointed to be proved.

When the hydrometer is constructed in this manner, if it is plunged in the liquors which are to be compared, it will not entirely sink, because it is supposed to be of a specific gravity, about or nearly equal with that of the fluid.

If,

If, therefore, the weight of the hydrometer is ſuch, that it will ſink in water as far as E, it will ſink ſtill deeper in lighter fluids; it will ſink for inſtance in wine as far as F; in ſpirits of wine as far as G, &c. But if it is plunged into liquors heavier than water, it will not ſink ſo far as E; for example, in beer it will only ſink to D, and always as much leſs as the liquor into which it is plunged is denſer and conſequently heavier.

By this proceſs it will be eaſily diſcovered, whether one kind of fluid is lighter than another with which it is compared; but the proportion cannot be accurately determined; for in order to that, it would be neceſſary to know exactly the proportion between the tube A C and the balls B and S; which is impoſſible according to the above mode of conſtructing the inſtrument; and it would alſo be further neceſſary that the tube A C ſhould be perfectly cylindrical, which never is the caſe. The moſt certain mode of acquiring this exact knowledge is, to operate always with equal volumes of fluids: and for this purpoſe, it is neceſſary to make uſe of Farenheit's hydrometer.

This inſtrument (fig. 2.) is compoſed of a ſmall oval glaſs bulb or bottle B; the neck of which A C is very ſmall, and terminates with a baſon D E, deſigned to receive ſmall weights.

The inſtrument is ballaſted by means of a ſmall ball of glaſs S fixed underneath it, in which there is depoſited ſome quickſilver. A ſmall grain of ſmalt (*a*) is fixed upon the neck, and the inſtrument is then complete.

In

In order to make uſe of this hydrometer, it is neceſſary to begin by knowing its exact weight, which ſhould be marked upon it, to prevent its being forgotten. The inſtrument is then plunged into diſtilled water; and by putting weights into the baſon D E, it is made to ſink as far as the grain of ſmalt (*a*). The weights which were made uſe of to produce this immerſion, added to the weight of the hydrometer, gives exactly the weight of the volume of water meaſured by the inſtrument. By repeating the ſame operation upon any other fluid, the weight of the volume of that fluid meaſured by the hydrometer, may be known with equal exactneſs. Hence it follows, that the quantity of theſe two volumes are equal, becauſe they are meaſured by the ſame inſtrument: the difference of their weight then will give the difference of their ſpecific gravity, or the relation between their denſities. To determine this relation exactly, the following proportion muſt be obſerved: The ſpecific gravity of the proved liquor, is to that of diſtilled water as the weight of a volume of that fluid meaſured by the hydrometer, is to the weight of the volume of water alſo meaſured by it. If the ſpecific gravity of the one is known exactly, the ſpecific gravity of the other may be determined by it, and alſo that of all other fluids which are proved in the ſame manner.

The whole of what has been advanced in this chapter, and in that of the firſt book upon ſpecific gravity, may be briefly ſummed up in the following propoſitions: Firſt, when two bodies are equal in

their

their magnitude, bulk, or volume, their ſpecific gravities are to each other as their denſities. So that one body has twice the ſpecific gravity of another, when it has twice the denſity of that other body comprized in the ſame ſpace or magnitude.

Secondly, when two bodies loſe an equal weight in the ſame fluid, they have the ſame magnitude or ſolid contents, whatever form they may aſſume, ſince they each loſe a weight equal to the bulk or volume of fluid which they diſplace.

Thirdly, the ſpecific gravity of bodies is inverſely as their bulk when their weights are equal. As one body has twice the ſpecific gravity of another, when with the ſame weight, it has only half the magnitude of that other body.

Fourthly, the ſpecific gravities of two bodies are in a direct proportion to their denſities, and in an inverſe proportion to their magnitudes. This propoſition is a neceſſary conſequence of two preceding, viz. of the firſt and third.

Fifthly, the ſame body will loſe a greater quantity of its weight in a fluid ſpecifically heavier than in a lighter one; becauſe it will always loſe a portion of its weight equal to the weight of that bulk of fluid which it diſplaces. It requires then a greater force to ſuſtain it in a lighter than in a heavier fluid: it will require more force to ſuſtain it in air than in water.

Sixthly, the ſpecific gravities of bodies of an equal weight (when weighed in a common balance) are proportionate to the weight which they loſe in the

the ſame fluid. So that of two bodies of equal weight, if the one loſes one-fifth and the other two-fifths of its weight in the ſame fluid, the ſpecific gravity of the firſt is to that of the ſecond as two to one.

Seventhly, if a body is of the ſame ſpecific gravity as a fluid, when immerſed in that fluid it will be in equilibrium with it, and remain at any depth at which it is placed.

Eighthly, if a body ſpecifically lighter than a fluid is plunged entirely into it, and then left to itſelf, it will remount with a force equal to the exceſs of weight which a volume of that fluid poſſeſſes above an equal bulk of the body immerſed.

Ninthly, the ſpecific gravity of a ſolid is to that of a fluid heavier than itſelf, and upon which it will ſwim, as the bulk of the immerſed part is to the bulk of the whole body. So that if the magnitude or bulk of the immerſed part is to the magnitude of the whole body as two to three, the ſpecific gravity of the ſolid is to that of the fluid as two is to three.

Tenthly, the weight and the magnitude of a body, and alſo the weight of a fluid ſpecifically heavier than the body, being given, ſuppoſe it is required to find the force requiſite to keep that body entirely immerſed in the fluid. As this force is equal to the ſpecific weight of the fluid, find, by means of the given bulk of the ſolid, and the known weight of a cubic foot of the fluid, by the rule of three, the weight of a bulk of the fluid equal to the bulk of the ſolid. Subſtract from this weight, the weight

weight of the solid, and the remainder will be the force required. For example, suppose it was required to find the force necessary to retain under water a solid of eight cubic feet in contents, and of four hundred pounds weight. Since a cubic foot of water weighs about seventy pounds, the weight of eight cubic feet of water is five hundred and sixty pounds; then if four hundred pounds are substracted, the one hundred and sixty remainder, is the force necessary to keep the solid immersed in the water, and to prevent it from rising to the surface.

Eleventhly, the weight of a body specifically heavier than a fluid, and the weight of that fluid specifically lighter, being given, suppose it is required to determine the cavity which that body should have, in order that it may swim upon the fluid.

The weight of a cubic foot of the fluid being given, the bulk of the portion of the fluid equal in weight to that of the body, is found by the rule of three. If then the cavity of the body is made so, that the bulk may be a little larger than the magnitude already found, the body will have less weight under the same magnitude than the fluid. For example, suppose that it is required to make a ball of iron of thirty pounds, and of such a magnitude as that it will swim upon water. Since the weight of a cubic foot of water is seventy pounds, a volume of water weighing thirty pounds will be three-sevenths of a cubic foot: hence it will be easy to find what the diameter of a sphere must be, the solid contents of which shall be three-sevenths of a cubic

foot.

foot. Therefore, the ball of iron muſt be made hollow within, and in ſuch a manner that its diameter may be greater than the diameter of a ſphere, the ſolid contents of which is three-ſevenths of a cubic foot: if this ball is made eleven inches three lines in diameter, it will ſwim. Hence we ſee that it is not neceſſary for a body to ſwim, that it ſhould be compoſed of matter ſpecifically lighter than water; it ſuffices that its bulk or volume ſhould be great and its gravity ſmall: for though copper is about eight times as heavy as water, yet military men have occaſionally employed boats of copper in conſtructing bridges for the paſſage of troops.

A copious table of ſpecific gravities is given in the appendix to this volume.

CHAP.

## Chap. III.

### HYDRAULICS*.

*Of the Discharge of Fluids through small Apertures.—The Discharge of Fluids through successive Pipes.—Artificial Fountains.—Pumps.—The Raising Pump.—The Forcing Pump.—The Sucking Pump.—The Compound Pump.—The Fire Engine.—Motion of Water in Conduit Pipes.—Oscillatory Motion of Water in a Siphon.—Oscillatory Motion of Waves.—Motion of Wheels acted upon by Water; and Construction of Water Mills.*

THE science which has for its object the motion of fluids is called hydraulics; and its immediate application is to furnish us with the *means* of conducting water from one situation to another, by canals or aqueducts, and to elevate it by pumps, jets-deaux, and other hydraulic engines, either for the purposes of ornament or use.

In treating of this subject I shall commence with the simplest principles, and shall first speak of the discharge of fluids through small apertures.

When water flows from a vessel which has a hole or aperture in the bottom, small in comparison to the width of the vessel, the water descends vertically, and the surface appears smooth, but at three or four inches from the bottom the particles turn from this

* Almost the whole of this chapter, and great part of the preceding, are translated from the first volume of Brisson's "Traite Elementaire de Physique," Chap. VIII.

this direction, and proceed on all sides with a motion more or less oblique towards the aperture. The same effect takes place when water flows through an aperture laterally. The tendency of the particles towards the aperture is a necessary consequence of their perfect mobility; for they will certainly be directed towards the point where there is the least resistance, and that point is the aperture.

It is also to be observed, that in this case, at a small distance from the bottom, a kind of funnel is formed in the water, the point of which corresponds to the center of the aperture; when, however, the water flows through a lateral orifice or aperture, there is formed only a kind of half funnel, which does not appear to commence till the surface is near touching the upper side of the hole. It is probable that the funnel begins to form itself from the first moment of the flow; but it does not become perceptible till the surface is only at a small distance from the bottom.

It appears also, that the funnel commences higher or lower, according to the width of the bottom; and that the formation of it is less prompt or less perceptible, according to the proportion of the aperture to the extent of the bottom. The funnel is also augmented by any roughness which may exist at the sides or bottom of the vessel.

Water flows out of a small hole in the bottom of a vessel with a velocity equal to that which a ponderous

 body

body acquires in falling from a height equal to the vertical height of the surface of the fluid above the aperture.

The same law takes place in a lateral orifice; for the pressure of the fluid is equal (at the same depth) in all directions, and consequently produces the same degree of velocity.

A fluid, in running out of an aperture, acquires a velocity sufficient to make it remount to a vertical height equal to that of the surface of the fluid above the aperture, in the same manner as a falling body acquires a velocity capable of making it ascend to the height from which it descended.

It is evident, from the theory of falling bodies, that if the velocity of the fluid in running through the aperture was uniformly continued, the fluid would move through a space double the *height of* the fluid above the aperture in the same time that a falling body would employ in descending from that height.

The height being the same, the velocity of the fluid in running out of the orifice will always be the same, whatever the species of the fluid may be, and whatever its density. It is true, that when the fluid has more density it presses more forcibly, but then the mass is more considerable, and it is evident, that when the moving powers are proportioned to the masses which they put in motion, the velocities are equal.

The quantities of a fluid discharged in the same

space

space of time through different orifices, supposing the vessels equally full during the whole of the experiment, are to each other as the products of the areas of the apertures by the square roots of the heights. For instance, it has been proved by experiment, that a circular orifice of an inch diameter, made in a thin vessel or partition, and under a surface of fluid four feet in height, will furnish, in one minute of time, five thousand four hundred and thirty-six cubic inches French.

If, therefore, it was an object to ascertain how much a circular orifice of two inches diameter, under nine feet of height from the surface of the water, would furnish in the same time, the following proportion must be employed (it must be observed, that the orifice of two inches is four times as great as an orifice of one inch, because the areas of circles are as the squares of their diameters):

$$1 \times \sqrt{4} : 4 \times \sqrt{9} :: 5436 : x$$

Or at length

$$2 : 12 :: 5436 : 32616$$

$$\begin{array}{r} 12 \\ \hline 2)65232 \\ \hline \end{array}$$

Therefore 32616 cubic inches of water will flow from an aperture of two inches in diameter in one minute, the orifice being made nine inches from the surface, which is supposed to be kept at that height the whole time.

 If

If a veſſel of a priſmatic form is filled with water, and permitted to empty itſelf entirely through an orifice at the bottom, and the time that it conſumes in emptying itſelf is obſerved; and if afterwards, having repleniſhed the veſſel, the water is made to flow through the ſame aperture, the veſſel being kept full the whole time, there will run out in this ſecond inſtance, during the ſame time that the veſſel took to empty itſelf at firſt, a quantity of water double that which runs out in the *firſt caſe*, for the abſtraction of the water produces a kind of funnel, which in this laſt caſe does not take place.

We often perceive water flow through lateral apertures, which, though ſmall in compariſon to the width of the reſervoirs, cannot be regarded as having all their points at an equal diſtance from the ſurface of the fluid; ſuch, for example, as the apertures through which water ſometimes flows in mills. The common method of determining the quantity diſcharged is as follows: ſuppoſe, in the firſt place, the aperture to be ſtopped up by a plate of metal, which is perforated with a number of holes; if each of theſe holes is regarded as particular and inſulated, the rapidity of the flow through each will be according to the correſpondent height of the fluid; then if the number of holes are multiplied *ad infinitum*, or, which will amount to the ſame thing, if the plate is ſuppoſed to be entirely taken away, the velocity at each point of the ſuppoſed orifice will be according to the correſpondent height of the fluid; and in eſtimating the quantity

quantity of water discharged, some attention must be paid to the inequality of the motion; yet it must not be asserted that this reasoning is entirely conclusive. In proportion as the sum of the small holes made in the plate is small in comparison with the size of the reservoir, the portions of water which flow through each hole are forced out by the absolute weight of the column above; but the moment that the number of apertures augment *ad infinitum*, and the streams of water which run through them become contiguous, it cannot be clearly said that the liquid flows in the same manner as through small insulated holes; yet as this hypothesis gives a result sufficiently conformable to experiments, it may be useful to preserve it, and the more so, as it leads to very simple calculations, and in all common questions this simplicity may be preferable to the minuteness of fractional operations.

The quantity of water which issues from these apertures in a given time is not so great as their size might at first suggest, because the stream is contracted by running out of each orifice, and that contraction extends to a distance nearly equal to half the diameter of the aperture; and the diameter of the contracted stream is to the diameter of the aperture a little more than as three to four, or as three and one-sixth to four, or nineteen to twenty-four; so that its area is to that of the aperture as ten to sixteen. It is nearly the same when water flows through lateral apertures. The contraction of the

ſtream is a proof of what has been before ſtated, viz. that withinſide a veſſel, the lateral particles direct themſelves towards the orifice with a motion more or leſs oblique; and this oblique motion may be decompoſed into two forces, the one parallel to the plane of the orifice, and which contracts the ſtream; the other perpendicular to the ſame plane, and the only one which produces the efflux.

This contraction occurs alſo when water is made to flow through pipes, and that at the entrance of the water into the pipe, and not at its exit, where the ſtream preſerves a cylindrical form. I ſhall prove that this contraction diminiſhes, in a ſenſible manner, the quantity of water which would naturally flow.

In order to aſcertain theſe facts by experiment, many have been made. In all the following inſtances the orifices, through which the water flowed, were pierced perpendicularly through plates of copper of about one-twenty-fourth of an inch thick, and the time of each experiment is reduced to one minute.

The

| | No. of cubic inches, furnished in 1 minute. |
|---|---|
| The constant height of the water above the center of each orifice was 11 feet 8 inches 10 lines. | |
| Exp$^t$. 1. Through an horizontal circular orifice of $\frac{1}{2}$ inch (6 lines) diameter - - | 2,311 |
| 2. Through ditto of 1 inch diameter - - - | 9,281 |
| 3. Through ditto of 2 inches diameter - - - | 37,203 |
| 4. Through an horizontal rectangular orifice of 1 inch long and $\frac{3}{12}$ inch wide - | 2,933 |
| 5. Through an horizontal square orifice of 1 inch the side - | 11,817 |
| 6. Through ditto of 2 inches each side of the orifice - | 47,361 |
| Constant height = 9 feet. | |
| 7. Through a lateral circular orifice of $\frac{1}{2}$ inch diameter - | 2,018 |
| 8. Through ditto of 1 inch diameter - - - | 8,135 |
| Constant height = 4 feet. | |
| 9. Through a lateral circular orifice of $\frac{1}{2}$ inch diameter - | 1,353 |
| 10. Through ditto, of 1 inch diameter - - - | 5,436 |
| Constant height = $\frac{7}{12}$ inch. | |
| 11. Through a lateral circular orifice of 1 inch diameter - | 628 |

It follows from the preceding table,

1. That the quantities of water discharged in the same time, by different apertures, under the same height of surface in the reservoir, are to each other nearly as the areas of the apertures. Compare together the results of the second and third experiments, of which the areas of the orifices are in the proportion of one to four, and it will be found that the quantities of water afforded, viz. nine thousand two hundred and eighty-one cubic inches, and thirty-seven thousand two hundred and three inches, are very nearly in the same proportion.

2. That the quantities of water discharged in the same time through the same aperture, under different heights of surface in the reservoirs, are to each other nearly as the square roots of the corresponding heights of the water in the reservoir above the center of the aperture. Compare together the results of the eighth and tenth experiments, where the heighths of the reservoirs are nine and four feet, the square roots of which are three and two, and it will be found that the two quantities of water, eight thousand one hundred and thirty-five cubic inches, and five thousand four hundred and thirty-six cubic inches, which run through the same orifice of one inch diameter under the different heights of nine feet and four feet, are to each other nearly in the proportion of three to two.

3. That in general the quantities of water discharged in the same time through different apertures, under different heights of surface in the reservoirs, are to each other as the areas of the apertures

-tures are to the square roots of the heights of water in the reservoirs.

4. That in consequence of the friction, the small apertures furnish a less quantity of water in proportion than the great ones, under the same height of water in the reservoir; because, comparatively to the extent of the area of each orifice, there are more points of friction against the sides of the orifice in the small than there are in the great ones; for the circumferences do not diminish so much as the areas.

5. That of many apertures of equal areas, that of which the circumference is the least will, on account of the friction, furnish more water than the others, under the same height of the reservoir; circular apertures are, for this reason, the most advantageous of all; for the circumference of a circle is the shortest line that can be made use of to inclose a given space; therefore there is less surface of friction relatively to the size of the area.

It is easy to perceive, that the quantity of water discharged in the table of experiments is not near so great as might be expected from the extent of the areas and the heights of the reservoirs. The quantity is in fact diminished by the friction, and still more by the contraction of the stream; for the velocity which is in proportion to the entire altitude of the fluid is not sensibly changed. Supposing, first, that the area of the stream is the same as that of the orifice; and supposing, secondly, that the stream is contracted, then the difference of the quantities afforded is as sixteen to ten; that is, supposing the

the area of the aperture to be diminiſhed in the proportion of ſixteen to ten, the diſcharge of the fluid out of veſſels kept equally full may be determined with ſufficient exactneſs. By the expreſſion, *an inch of water*, is underſtood the quantity which flows out of a circular and lateral orifice of one inch diameter, the ſurface of the water being conſtantly kept ſeven-twelfths of an inch above the center of the orifice. This is the caſe with the eleventh experiment in the preceding table, where it appears that the quantity of water furniſhed is ſix hundred and twenty-eight cubic inches. M. Mariotte, who made the ſame experiment, found the quantity to be a little more; but it is probable that he might commit a ſmall error, becauſe the experiment I have juſt cited was made, M. Briſſon informs us, with the utmoſt care and attention. A (*French*) pint of water, he adds, inſtead of weighing two pounds, as is commonly believed, is proved to fall ſhort of that weight conſiderably, as will be evident by ſtrictly examining that experiment.

Theſe facts being premiſed, I ſhall requeſt the attention of the reader, ſecondly, to the diſcharge of fluids through additional pipes.

When, inſtead of cauſing water to paſs through an aperture made in a thin ſubſtance, it is made to flow through an additional vertical pipe of the ſame diameter with the orifice, the quantity of water diſcharged is more conſiderable, becauſe the contraction of the ſtream is greater in the firſt caſe than in the ſecond.

In

In the following experiments, the conftant height of the water in the refervoir above the upper bafe of the additional vertical pipe is 11 feet $8\frac{10}{12}$ inches (French) and the diameter of the pipe one inch.

| | The variable heights of the tube expreffed in lines. | | Number of cubic inches of water difcharged in one minute. |
|---|---|---|---|
| | *Lines.* | | |
| Exper. 1. | 48 | The water running through a full pipe. | 12,274 |
| 2. | 24 | | 12,188 |
| 3. | 18 | | 12,168 |
| 4. | 18 | The water not filling the pipe. | 9,282 |

It appears from this table of experiments, that the longer the vertical pipe is, the greater will be the quantity of water difcharged, becaufe the contraction of the ftream is lefs, as may be feen by comparing the three firft experiments. There is always, however, fome contraction, though the water appears to flow out of a full pipe.

In comparing the quantities of water difcharged in the third and fourth experiments, it will appear, that the two quantities, 12,168 cubic inches and 9,282 cubic inches, are to each other nearly in the relation of thirteen to ten; but it has been obferved before, that the quantity of water difcharged through an aperture made in a thin fubftance, if the ftream was not contracted, would be to the quan-

tity of water discharged through the same orifice, if the stream was contracted, nearly as sixteen to ten. Hence then it may be concluded, that the height of the water in the reservoir and the different apertures being the same, the quantity of water discharged through an orifice made in a thin substance, in which there was no contraction of the stream, the quantity of water discharged through an additional pipe, and the quantity which would flow through an orifice made in a thin partition, in which there was a contraction of the stream, are to each other nearly as the three numbers, sixteen, thirteen, ten, and these proportions are found sufficiently accurate for common purposes.

Hence also it may be inferred, that additional pipes counteract only in part the contraction of the stream. The most sensible of all contractions of this nature is that which takes place when water flows from a large reservoir through a small aperture made in a thin substance.

If the additional pipe, instead of being vertical, or placed in the bottom of the vessel or reservoir, is horizontal, or placed in the side, it will afford the same quantity of water, provided that it is of the same length, and that the exterior aperture is placed at the same distance below the surface of the water in the reservoir.

If the additional pipe, instead of being cylindrical, is conical, having its largest base attached to the side of the reservoir, it will produce a much greater quantity of water. The most advantageous form, indeed, for procuring the greatest quantity of water

in a given time through a certain aperture, is that which the ſtream itſelf naturally aſſumes in coming out of an aperture in a thin ſubſtance; that is, the form given to the pipe ſhould be that of a truncated cone, the diameter of the ſmaller baſe of which ſhould be the ſame as that of the aperture through which the water is to flow.

It is neceſſary alſo, that the area of the ſmaller baſe ſhould be to the area of the greater as ten to ſixteen; and the diſtance between the two baſes ſhould be nearly equal to half the diameter of the greater baſe. The remainder of the length of the pipe may be either cylindrical or priſmatic. The diſcharge will then be equally abundant with that which would take place through an aperture equal to the ſmaller baſe made in a thin partition, and in which the ſtream ſuffered no contraction. This form may be applied to practice whenever it is required to draw a certain quantity of water from a river by an aqueduct, &c. through a canal or lateral pipe.

If we compare the different quantities of water diſcharged through additional pipes of different diameters with different altitudes of the water in the reſervoirs, we ſhall have the reſults ſtated in the following table, the additional pipes being ſuppoſed to be two inches long, and vertical, or placed in the bottom of the reſervoir.

The

| The constant height of the water above the aperture. | The diameter of the additional pipes in twelfths of an inch (lines). | | No. of cubic inches discharged in one minute. |
|---|---|---|---|
| Ex. 1. | 552 lines. | 6 | The water running through a full pipe. | 1,689. |
| 2. | 552 lines. | 10 | The water running through a full pipe. | 4,703. |
| 3. | 552 lines. | 6 | The water not following the sides. | 1,293. |
| 4. | 552 lines. | 10 | The water not following the sides. | 3,598. |
| 5. | 288 lines. | 6 | The water running through a full pipe. | 1,222. |
| 6. | 288 lines. | 10 | The water running through a full pipe. | 3,402. |
| 7. | 288 lines. | 6 | The water not filling the tube. | 935. |
| 8. | 288 lines. | 10 | The water not filling the tube. | 2,603. |

The first inference from these experiments is, that the quantity of water discharged by different additional pipes, under the same height of water in the reservoir, is proportional to the areas of the apertures, or to the squares of their diameters.

Secondly, it appears that the quantities of water discharged through additional pipes of the same diameter, under different altitudes of water in the reservoir, are proportional to the square root of the altitude.

Thirdly, that in general the quantities of water discharged in the same space of time through different additional pipes, under different heights of water in the reservoir, are to each other nearly as the product of the square of the diameters of the pipes by the square root of the altitude of the reservoirs.

The

The efflux of water, therefore, through additional pipes, follows the ſame laws as water when diſcharged through apertures made in thin ſubſtances. On theſe experiments the following table was formed, of the quantities of water diſcharged through a given aperture made in a thin ſubſtance, ſuppoſing the ſtream to ſuffer no contraction, or through the ſame aperture with a contraction of the ſtream, or through the ſame aperture with an additional pipe.

| Conſtant height of the water in the reſervoir above the aperture, expreſſed in (French) feet. | Cubic inches of water diſcharged in one minute through an aperture of one inch diameter without any contraction of the ſtream. | Cubic inches of water diſcharged in one minute through an additional pipe of one inch diameter and two inches long. | Cubic inches of water diſcharged in one minute through an aperture of one inch diameter with a contracted ſtream. |
|---|---|---|---|
| 1 | 4381 | 3539 | 2722 |
| 2 | 6169 | 5002 | 3846 |
| 3 | 7589 | 6126 | 4710 |
| 4 | 8763 | 7070 | 5436 |
| 5 | 9797 | 7900 | 6075 |
| 6 | 10732 | 8654 | 6654 |
| 7 | 11592 | 9340 | 7183 |
| 8 | 12392 | 9975 | 7672 |
| 9 | 13144 | 10579 | 8135 |
| 10 | 13855 | 11151 | 8574 |
| 11 | 14530 | 11693 | 8990 |
| 12 | 15180 | 12205 | 9384 |
| 13 | 15797 | 12699 | 9764 |
| 14 | 16393 | 13197 | 10130 |
| 15 | 16968 | 13620 | 10472 |

III. There

III. There is no application of the doctrines of hydraulics more surprising, or more gratifying to the eye, than that which is seen in the variety of artificial fountains, or jets d'eau, which the ingenuity of man has been able to construct for ornament in general, and for use in some instances, particularly in warm climates. The principles on which these are constructed it will not be difficult, after what has been stated, fully to comprehend.

Whatever may be the direction of the jet or fountain, the quantity of water expended will be the same, provided that the adjutage*, and the height of the reservoir above the adjutage, is the same. This is a necessary consequence of the equal pressure of fluids in all directions.

Water, when discharged through an ajutage, however small it may be, has a velocity sufficient to raise it to the height of the surface of the water contained in the reservoir; so that a vertical jet d'eau throws up the water as high as the reservoir whence it proceeds, if nothing obstructs it.

There are, however, many causes which contribute to diminish the elevation of water by jets d'eau. First, the friction in the pipes from the reservoir to the ajutage; secondly, the friction against the circumference of the aperture; thirdly, the resistance of the air to the motion of the column; fourthly, the gravity of the particles of water themselves, which, in rising, lose some of their velocity, and recoil upon those which succeed them.

* A tube which is fitted to the mouth of the vessel through which the fountain is played.

Thus,

Thus, by inclining the pipe a little, we find that the water will riſe higher than when it is exactly vertical; but in this caſe, the effect is not ſo agreeable to the eye of the ſpectator, as when the water which riſes above the pipe into the air falls perpendicularly, in a manner, back upon itſelf.

When the ajutage is placed in an oblique direction to the horizon, the force of the projection and the gravity of the water cauſe the ſtream which aſcends into the air to form a parabola, the amplitude of which is in proportion to the height of the reſervoir.

When the ajutage is placed horizontally, the water forms a ſemi parabola.

Fountains elevate the water in proportion as the aperture of their ajutages is large; becauſe, firſt, if two jets d'eaux proceeding from the ſame reſervoir, and flowing from their ajutages with an equal degree of velocity, the greater will, in the firſt place, experience leſs friction; and ſecondly, it has a greater maſs, and conſequently more power to overcome the obſtacles which may oppoſe it.

But, though large jets d'eau elevate water higher than ſmall ones, they do not expend a greater quantity in proportion; for the quantity of water diſcharged is as the product of the aperture of the ajutage by the degree of velocity at the time of the diſcharge; and this velocity is the ſame in both, no allowance being made for the friction.

In order to make large fountains elevate water higher than ſmall ones, it is evidently neceſſary that the conducting pipes ſhould be ſufficiently large to furniſh water in abundance; for if they are ſmall,

 experience

experience proves that the ſmall fountains in that caſe will elevate water higher than larger ones; it follows then, that the diameter of the pipe, which conveys the water, ſhould be in proportion to that of the ajutage, in order to elevate the water to the greateſt poſſible height.

If we compare two different jets d' eau, and are deſirous that each ſhould elevate water to the greateſt poſſible height, it is neceſſary that the ſquares of the diameters of the conduit pipes ſhould be in proportion to each other in the compound ratio of the diameters of the ajutages and the ſquare root of the altitudes of the reſervoirs. Thus, if it is known by experiment what the diameter of a conduit pipe ſhould be, to ſupply an ajutage of given dimenſions, it may be eaſily determined what the diameter of another pipe ſhould be to furniſh another ajutage of a determinate ſize, the height of the reſervoir being alſo given.

It has been proved by experiments, that when the diameter of the ajutage is half an inch, and the height of the reſervoir fifty-two feet, the diameter of the pipe which conducts the water ought to be three inches and a quarter; and that for an ajutage of half an inch diameter, the height of the reſervoir being ſixteen feet, the diameter of the pipe ought to be about two inches and one-third. There is no inconvenience in making the conduit pipe of a greater diameter than is required by this rule; but on the contrary, there would be an inconvenience in making it of a ſmaller diameter.

Sometimes the ajutage is made in the form of a cone, and ſometimes in that of a cylinder; but thoſe

those who conceive that it is indifferent in which of those forms it is made are mistaken, for the cylindrical form is by far the most disadvantageous.

By comparing many experiments made upon artificial fountains, it has been determined, that the differences between the altitudes of vertical jets and the height of their reservoirs are to each other as the squares of the altitudes of the former. If then it is known what quantity of water a jet elevates at a certain height of the reservoir, the quantity which any other jet of a given height will elevate, compared with the height of its reservoir, may be easily found by the rule of single proportion.

When it is necessary to bend the conducting pipes, the utmost care should be taken to avoid bending them at right angles, for the striking of the current against these angles very considerably diminishes the velocity.

The following table will greatly facilitate the application of these principles.

The heights of jets, and the correspondent heights of reservoirs, are found in the two first columns. The third column contains in (Paris) pints, of which thirty-six make a cubic foot, the quantities of water discharged in one minute through an ajutage of half an inch diameter, relatively to the heights in the second column. The quantity discharged through an ajutage of half an inch diameter being known, the quantity which will be discharged by any other ajutage, under the same height of the reservoir, may be found by single proportion; for it has already been proved, that the quantities of water discharged are to each other as

the areas of the ajutages, or as the ſquares of their diameters. In the fourth column are found the diameters for the conducting pipes of an ajutage of half an inch diameter, according to the heights in the ſecond column. The diameters of pipes for other ajutages, and other heights of the reſervoir, are found by following the preceding rule.

Fractions are not obſerved in the calculations for the two laſt columns.

| The heights of jets, expreſſed in feet. | The heights of reſervoirs, in feet and inches. | | Quantities of water diſcharged in one minute through an ajutage of half an inch diameter, in pints. | Diameters of the pipes, according to the 2d and 3d columns, in lines. |
|---|---|---|---|---|
| *Feet.* | *Feet.* | *Inches.* | *Pints.* | *Lines.* |
| 5 | 5 | 1 | 32 | 21 |
| 10 | 10 | 4 | 45 | 26 |
| 15 | 15 | 9 | 56 | 28 |
| 20 | 21 | 4 | 65 | 31 |
| 25 | 27 | 1 | 73 | 33 |
| 30 | 33 | 0 | 81 | 34 |
| 35 | 39 | 1 | 88 | 36 |
| 40 | 45 | 4 | 95 | 37 |
| 45 | 51 | 9 | 101 | 38 |
| 50 | 58 | 4 | 108 | 39 |
| 55 | 65 | 1 | 114 | 40 |
| 60 | 72 | 0 | 120 | 41 |
| 65 | 79 | 1 | 125 | 42 |
| 70 | 86 | 4 | 131 | 43 |
| 75 | 93 | 9 | 136 | 44 |
| 80 | 101 | 4 | 142 | 45 |
| 85 | 109 | 1 | 147 | 46 |
| 90 | 117 | 0 | 152 | 47 |
| 95 | 125 | 1 | 158 | 48 |
| 100 | 133 | 4 | 163 | 49 |

IV. From

IV. From objects of mere pleasure and ornament, our attention is next solicited to an invention of eminent utility, and of ancient date, though the modern improvements are very considerable even in this branch of mechanics.

*Pumps* are hydraulic engines, designed for the purpose of elevating water; they are composed of hollow cylinders AB (Plate VII. Fig. 3.) or E F (Plate VIII. fig. 1.) of an equal diameter throughout their whole length, which is called *the body of the pump*, and in which a kind of stopple I, called the *piston*, is made to slide, or move up and down. The piston is put in motion by means of a rod of metal X *x*, at the extremity of which X the handle is placed, and elevated by the lever X Y, or by some other contrivance; to this is annexed a pipe A T (Plate VII. Fig. 3.) to conduct the water to the height required; and, lastly, the suckers S *s*.

There are several kinds of pumps; some are called sucking pumps and others forcing pumps, and there are others which are at the same time both sucking and forcing pumps.

The *raising pump* is composed of the body of the pump A B, (Plate VII. Fig. 3.) to the lower part of which is affixed the end of a pipe B N, open at the bottom, or (which is still better) pierced with holes its whole length, in such a manner that large pieces of dirt and rubbish may be prevented from entering the body of the pump. At the union of this end of the pipe with the body of the pump is placed a valve or sucker *s*, which, when raised up by the pressure of the water beneath, permits the

fluid to ascend into the body of the pump, but which, by being pressed down again by the action of the pump, prevents effectually the efflux of the water by the same aperture. In the body of the pump there is a box or piston I, pierced quite through, furnished at the upper end with a sucker S, and joined at *x*, by the assistance of a head somewhat in the form of that of a pair of compasses, to the rod *x* X, which enables it to act by the aid of a lever X Z Y. At the upper part A of the body of the pump is placed the raising pipe A T, which has its spout in T This pump ought to be placed in a well or bason, in such a manner that the body of the pump A B should be entirely under the surface of the water A A.

Now if the piston I is raised by lowering the extremity Y of the lever Y Z X, so that the lever may assume the position *y* Z *u*, the piston will rise up the body of the pump, where it will create an imperfect vacuum equal to the distance X *u*, and consequently the water beneath will raise the sucker *s*, and will pass out of the bason into the pump. When the piston is lowered again, this pressure causes the sucker *s* to close, and the sucker S to rise up; hence the water which was below the piston is then above it. By a second exertion of the piston, this quantity of water is elevated, and by the same mechanism a fresh quantity is permitted to pass into the pump, and afterwards to rise above the piston, in the same manner as the first portion was raised; so that by a certain number of exertions of the piston, the raising pipe A T is filled. When

this

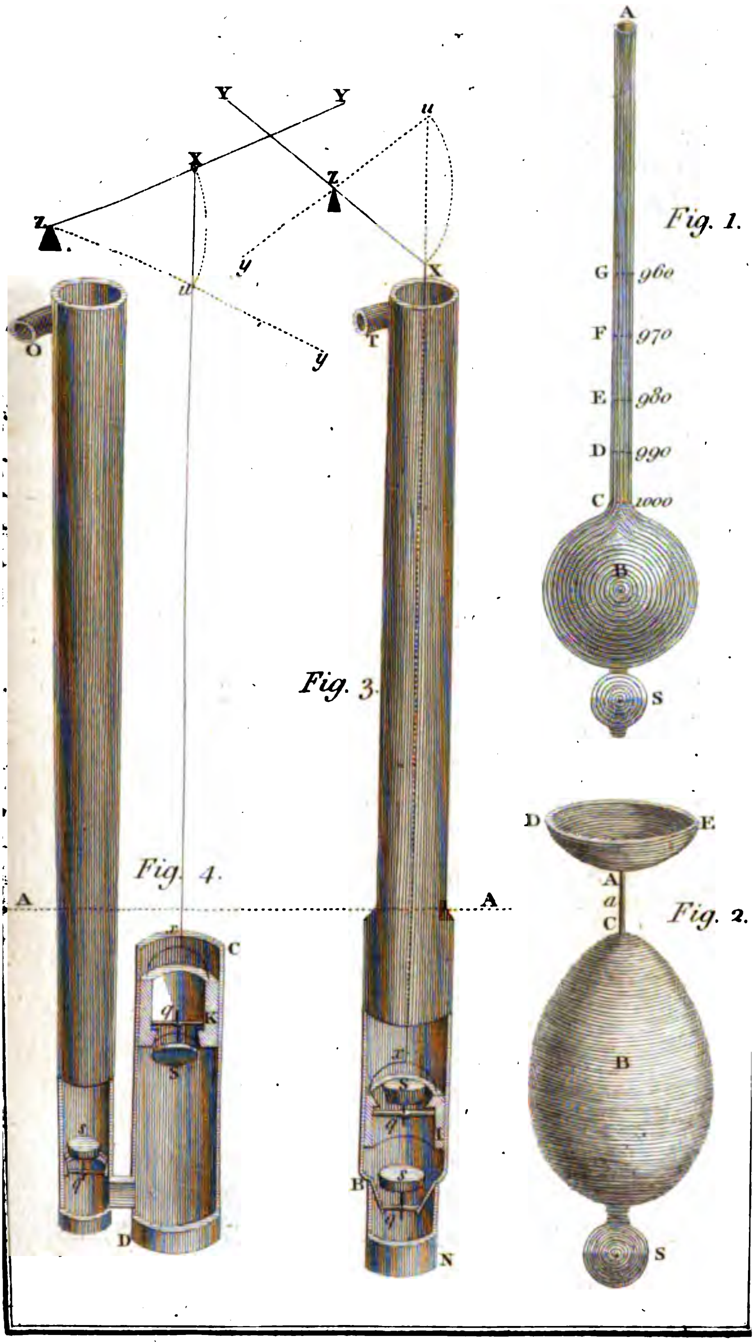
Fig. 1.
A
G 960
F 970
E 980
D 990
C 1000
B
S
Fig. 2.
D
E
A
a
C
B
S
Fig. 3.
Y
Y
u
X
Z
Z
y
y
u
X
T
O
A
A
C
K
S
q
x
s
q
B
N
D
I
Fig. 4.

this is accomplifhed, at every exertion or ftroke of the pifton there is ejected at the fpout or difcharging pipe T a mafs of water equal to a cylinder, the bafe of which is equal to the width of the pifton, and of a height equal to the fpace through which the pifton paffes in the body of the pump. This fpace is commonly called the play of the pifton.

It is not difficult to eftimate the weight of the column of water with which the pifton is charged, when the raifing pipe is full, and confequently the force which is neceffary to be exerted in Y in order to work the pump. It has been obferved before, that fluids prefs in proportion to their perpendicular height, and the width of the bafe which oppofes their defcent. In a pump, this bafe is the pifton, and the perpendicular height is that of the raifing pipe above the furface of the water; fo that when the raifing pipe is full, the charge upon the pifton is equal to the weight of a cylinder of water, the diameter of which is equal to that of the pifton, and the height equal to that of the raifing pipe above the furface of the water, whatever may be the diameter of the mounting pipe; and this charge or weight upon the pifton is eafily calculated, when it is known that a cylinder of water of one foot diameter and one foot high weighs about fifty-five (French) pounds.

It follows, therefore, that the weight of a column of water is not diminifhed by diminifhing the diameter of the raifing pipe; but that, on the contrary, the refiftance which ought to be overcome is even augmented on account of the increafe of the friction, which is more confiderable in fmall pipes

 than

than in large ones, because the relative surfaces augment as the diameters diminish. Thus, only for the expence, it would be wrong to make, as is commonly done, the raising pipe smaller than the body of the pump; on the contrary, it would be better to construct it of a diameter greater than that of the body of the pump, as the friction would be proportionably diminished.

The *forcing pump* is composed of the body of the pump C D, (Plate VII Fig. 4.) stopped close at the bottom, but entirely open above, and in which is a piston K, which only differs from that of the pump already described in this, that its sucker S is placed at the bottom instead of the top. This piston, like that of the pump just mentioned, is put in action by means of the lever Y X Z, which has its point of support in Z. The raising pipe A O is placed at the side of the body of the pump, with which it communicates, and is furnished with a sucker *s* in its lower part, and with a spout O at its upper extremity. This pump, as well as the preceding, ought to be immersed in a well or bason in such a manner that the body of the pump C D should be entirely under the surface of the water A A.

The water fills the body of the pump by falling through the aperture C, and by passing over the piston K, the sucker of it S, considering its position, will naturally open. If the piston K is lowered, by placing the lever Y X Z in the position *y u* Z, the resistance of the water against the sucker S will close it immediately. This water then,

then, being incapable of repassing above the piston, is forced up the pipe A O, by raising up the sucker *s*. As soon as the piston is raised again, the sucker *s* is closed by the pressure of the water which is above, and the sucker S is opened by its own weight. A new mass of water then passes below the piston, which, by a second depression of the piston, is forced to pass, like the first, into the pipe A O; so that by a certain number of strokes of the piston that pipe becomes full of water, which is then discharged at the spout O as in the pump already described. If the pistons in both of them are of the same diameter, and the raising pipes of the same perpendicular height, the weight of the two columns of water will be equal, and the two pumps will require the same power to work them; for in that case it requires the same power to elevate the piston charged with a column of water as it does to force the column of water with the piston.

The sucking* pump (Plate VIII. Fig. 1.) is composed of the body of the pump E F, open above, and with a pipe of aspiration or sucking pipe F P adapted to the lower part. At the union of this pipe with the body of the pump is a sucker *s*, designed to permit the water, while the piston is raised, to enter through the pipe of aspiration P F into the body of the pump F E, and to prevent it, while the piston is lowering, from being discharged the same way. In the body of the pump is a

* So called, because it was originally supposed, but erroneously, to act by suction.

piston

piston L, made like that at I in Plate VII. Fig. 3. and which is put in action in the same manner by the assistance of the lever X Z Y. This pump should be placed in such manner as to have only the lower extremity of the aspiration pipe F P plunged into the water.

While the pump remains inactive, the two suckers S and *s* are naturally closed from their own weight. If the piston L is raised up by means of putting the lever X Z Y in the situation *x* Z *y*, the column of air which rests above is elevated, and the air which is closed up in the aspiration pipe, from the surface of the water *a* to the piston, having then more space to occupy, becomes more rarified than the external air. This last then presses more forcibly upon the surface of the water *a*, and causes it to rise in the aspiration pipe, till the interior air has regained its former density by occupying less space. Thus, after several strokes of the piston, the water reaches the body of the pump, and passes over the piston, by raising up the suckers *s* and S, one after another, and the piston, by its subsequent elevation, forces the water to escape at the spout E.

As it is the pressure of the air which causes the water to rise in this pump, and as this pressure can sustain only a column of water of about thirty-two feet, it is clear that the aspiration or sucking pipe should not exceed that length. In common practice it is indeed seldom made so long as thirty-two feet. In order that the pressure of the atmosphere may be such as to sustain a column of water of that height, it

it is neceſſary, firſt, that the ſucking pump ſhould be made with the greateſt exactneſs, and that it ſhould continue in a perfect ſtate; ſecondly, that it ſhould be placed upon the level of the ſea, or very near it, becauſe it is there that the preſſure of the atmoſphere is moſt forcible; thirdly, that the preſſure of the air ſhould not vary; but in general all theſe circumſtances are not required. Mechanics are ſatisfied, in general, with making the aſpiration pipe twenty-three or twenty-four feet long. If it is neceſſary to elevate water to a greater height, the forcing pump is more commodious for that purpoſe. The latter, it is true, is ſubject to ſeveral inconveniencies. It is neceſſary to place the body of the pump either in wells or in a baſon; and when it is required to repair it, which often happens, one of two things is neceſſary, either to empty the well or the baſon, or to draw up the body of the pump, which is extremely troubleſome and expenſive. To remedy theſe inconveniencies, the beſt and moſt uſual mode is, when water is to be elevated from a great depth, to make the pump at once both a forcing and ſucking pump, in the manner which I ſhall preſently explain.

In the year 1766 it was reported, through the channel of the public papers, that at Seville, in Spain, a ſimple ſucking pump had been conſtructed, which elevated water to the height of ſixty feet, and it was conſequently concluded, that the world had till then been notoriouſly impoſed upon by the current maxim, that the preſſure of the air could raiſe a column of water only to the height of thirty-two feet,

feet. M. Brisson has carefully examined into the fact, and his explanation is curious and interesting.

An ignorant tinman, at Seville, had made a sucking pump sixty feet long, because he had occasion to elevate the water to that height. When the pump was fixed in its place, and put in action, he was unable to make the water rise into the body of the pump. Enraged at this disappointment, he gave it a blow with his hammer, which produced a a small aperture in the aspiration pipe at about ten feet above the surface of the water in the bason. Immediately a small portion of water arrived at the body of the pump. After this process it was reported, that a sucking pump had been constructed, which elevated water to the height of sixty feet; but the reader will be enabled to judge of the truth of this assertion from the following observations:

Let us suppose that the aspiration pipe, P F (Plate VIII. Fig. 1.) had from *a*, the surface of the water of the bason, to F, a distance of sixty feet, and that after a certain number of strokes of the piston, the water rises to *c*, thirty-two feet high; if then a small hole is made at *b*, ten feet above the surface of the water, the air which enters at this hole, and presses in all directions, will cause the column of water of ten feet, which is below *b*, to fall into the bason, and the pressure of the air upwards at *b* has only a column of water of twenty-two feet to support.

But that pressure is capable not only of raising that column to the height of sixty feet, but even to the

the height of eight thouſand feet; for air, near the ſurface of the earth, is eight hundred times leſs denſe than water, and ſuppoſing (which is not the caſe) it was not diminiſhed in elevating, then the ten feet of water, cut off by the preſſure of the air at *b*, downwards, would be more than equivalent to eight thouſand feet of air. The column of air, therefore, which preſſes at *b*, will be too ſtrong for more than eight thouſand feet; thus the twenty two feet of water remaining above will not be in equilibrium with the column of air till after it has riſen higher than eight thouſand feet.

In order to have a ſecond portion of water with a pump of this conſtruction, it is in the firſt place neceſſary to ſtop the aperture which was made at *b*, then to give ſeveral ſtrokes with the piſton to elevate the water as high as *c*; and laſtly, to open again the orifice at *b*. Obſerve the ſimplicity of this proceſs for raiſing ſo ſmall a quantity of water! for it is neceſſary that the aſpiration pipe ſhould be of a very ſmall diameter, otherwiſe the column of water would break, and the air would paſs through, and not one drop of water could be raiſed into the body of the pump. This fact (adds M. Briſſon) may ſerve to convince thoſe who are fond of novelty, that before an opinion generally received is pronounced to be falſe, it is neceſſary to think twice at the leaſt. A ſhort time after the conſtructing of this pump at Seville, M. Bellangé, a goldſmith in Paris, made one in imitation of it, to which he gave the additional property of throwing water fifty-five feet high, by means of a continued *jet* or

ejecting pipe, though the machine was only a simple sucking pump.

To a small bodied pump of two inches and one-twelfth in the interior diameter, the piston of which had eight inches play, he adapted an aspiration pipe of ten-twelfths of an inch diameter, and fifty-six feet long; this pipe was furnished with a sucker at its junction with the body of the pump, and with another at its lower extremity. This extremity was plunged into a tun full of water. M. Bellangé had made a small perforation in this pipe of about one twenty-fourth of an inch diameter, at twelve or fifteen inches above the surface of the water in the tun. The apparatus being disposed of in this manner, he moved the piston gently, but the water did not rise; the small hole furnished a sufficient quantity of air to fill the aspiration pipe. He then moved the piston with great velocity; the small hole could not, in so short a space of time, furnish a sufficient quantity of air to fill the pipe; a little water rose and mixed itself with the air, so that the column became composed of small cylinders, alternately of air and water, and though it was fifty-five feet high, it was much short of the weight of a column of water thirty-two feet high. If we calculate, therefore, according to the diameter of the body of the pump, and the extent in which the piston played, what quantity of water this pump would have furnished if the air had not entered, and then compare this quantity with that which it really furnished, we shall find that the latter is greatly inferior;

for

for in six minutes five hundred and thirty strokes of the piston may be given, which would furnish only thirty six pints of water; this pump, therefore, would not furnish the eighth part of the water which it ought to do upon the common principles of the sucking pump; so that though the construction might appear to be more ingenious, it was not in reality to be preferred to that of Seville.

The *compound forcing pump* is composed of the body of the pump G H, (Plate VIII. Fig. 2.) open above, and the aspiration pipe H V adapted to the lower end. At the union of this pipe with the body of the pump is a sucker S, designed for the same use as in the simple sucking pump. In the body of the pump is a piston M, not pierced as the preceding, but solid, and put in action by the aid of the rod *x* X, and of the lever Y X Z, which has its point of support, or fulcrum, in Z. At the side of the pump, and towards the bottom of its body, is adapted a raising pipe H R, furnished with a sucker *s* near its base, and with a spout R near its superior extremity. This pump ought to be placed in such a manner that the lower extremity only of the aspiration pipe H V should be immersed under water.

It is easy to perceive that the first action of this pump will be the same as that of the sucking pump, which has been described; for if the piston M is raised by putting the lever Y X Z in the situation *y u* Z, the column of air which rests above will be elevated; the air which is in the aspiration-pipe will become, by that means, rarer

rarer than the exterior air. The latter then presses more forcibly upon the surface of the water A A, and carries it, after some strokes of the piston, into the body of the pump; when it is arrived there, if the piston M is lowered, the sucker S will close, and the water is forced along the raising-pipe H R, by the rising of the sucker *s*, which, as soon as the pressure ceases, falls again from its own weight and that of the water above it.

This pump is very convenient, on account of its body being placed out of water, which affords an opportunity of making the necessary repairs with facility, and also on account of its being capable of carrying water to any height which may be required: in order to effect this, all that is necessary is, to lengthen the raising-pipe, and to augment the power which puts the pump in action. I believe this is at present the most usual form of what are called forcing pumps in this country.

The fire engine is an hydraulic engine, which may be classed with the pump that I have now described. It is at once a sucking and forcing pump, but has a continued *jet*, or ejecting pipe, though it has only one body. The essential parts of this pump are composed, like the compound pump, (Plate VIII. Fig. 2.) with this difference, that its aspiration pipe is much shorter, and that instead of a solid raising pipe it has a leathern tube of a convenient length. This pump (Plate IX. Fig. 1.) is then composed of the body of the pump A H, open above, and to the lower part is adapted the aspiration

pipe

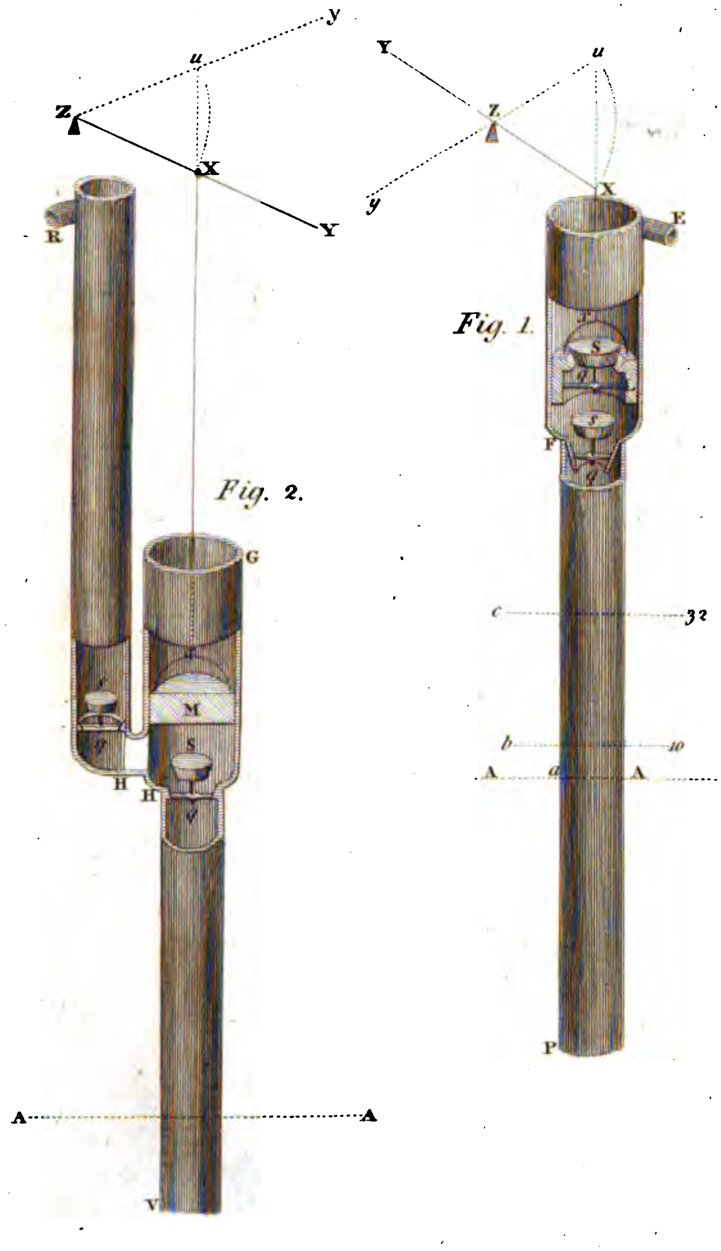

Fig. 1.
Fig. 2.
y
u
Z
X
Y
R
G
M
S
H
H
V
A
A
E
F
P
c
32
b
10
a

H T. At the union of this pipe with the body of the pump is placed a ſucker S, deſigned to prevent the water, which has once paſſed into the body of the pump, from returning into the baſon. In the body of the pump is a piſton M, not pierced but ſolid, and which is put in motion by the aid of a metal rod *x* X, and of a lever Y X Z, which has its fulcrum or point of ſupport in Z. Towards the bottom of the pump, in the ſide, is an aperture C, which is covered again by means of a valve *c l*, of which the tail *l* is the ſpring, and which is fixed on with a ſmall ſcrew. This valve is deſigned to prevent the water, which is expelled from the body of the pump, from entering again when the piſton M is raiſed. The body of the pump is ſurrounded with a pipe A B D E, about two or three inches more in diameter than the body of the pump, and the intermediate ſpace between them is filled with air. To the lower part of this pipe, and upon the ſide, is adapted another ſmall crooked pipe E R, furniſhed at the end R with a ſucker *s*, and with a ſcrew ferule, intended to receive a nut, by means of which the leathern pipe is joined to this end of the engine, and which ſerves inſtead of the raiſing pipe in the common forcing pump. All this apparatus is placed (as may be ſeen in Plate IX. Fig. 2.) upon a box or caſe N O lined with lead, which contains the water. The croſs bar Q ſupports the upper end F (Fig. 1.) of the body of the pump, which, for that purpoſe, is of a ſmaller diameter than the reſt; and the lid L (Fig. 2.) of the box has an aperture in the middle,

 to

to admit the aſpiration pipe H T to paſs through it.

From this explanation it will be evident, that if the piſton M is raiſed up by putting the lever Y X Z in the ſituation *y u* Z, the ſucker *s* and the valve *c*, placed in C, will be cloſed by the preſſure of the exterior air. This ſame preſſure, exerciſing its force upon the ſurface of the water V V, obliges it to paſs into the body of the pump by raiſing up the ſucker S. It then acts as a ſucking pump; but when the piſton M is lowered, its preſſure cloſes the ſucker S, and opens the valve which is in C; the water then paſſes, not only into the leathern pipe *a b d*, (Fig. 2.) by raiſing up the ſucker *s* (Fig. 1.) but alſo into the ſpace between the body of the pump and the pipe which incloſes it, by riſing towards I K, and compreſſes the air which is confined there. Immediately after the piſton M is raiſed again, that air, being no longer compreſſed, unfolds itſelf by its elaſticity, acts upon the water which is between the body of the pump and the pipe which incloſed it, and forces it alſo into the leathern pipe, ſo that when the piſton is lowered, the water is forced by the piſton itſelf, and when it is raiſed, the water is forced by the elaſticity of the air, which furniſhes a continued ſtream, though the pump has only one body or principal tube.

It is evident that theſe fire engines ſhould be able to furniſh a continued ſtream, and this can only be effected by employing the elaſticity of the air, while the piſton is riſing; but in order to effect this, a double force is required to put the pump in motion; in

other

other words, a force capable of expelling the column of water, and an equal force to compreſs the air. But this is not an inconvenience, for, in caſe of fire, it very ſeldom happens that hands are wanting to aſſiſt; on the contrary, it frequently happens that the aſſemblage of people is rather too numerous.

Such is the engine which M. Briſſon has deſcribed, and it is, I preſume, that which is in common uſe in France. Its ſimplicity is admirable; yet I apprehend that our Engliſh fire engines are more powerful, and furniſh a more uninterrupted ſtream or current of water through the leathern pipe. In Fig. 3. is a repreſentation of our improved fire engine. This, the reader will ſee, is wrought by two forcing pumps, which act alternately; and the ſtream is made continual from the ſpring of air confined in a ſtrong metal veſſel C C, in the fire engine A B, fixed between the two forcing pumps D and E, wrought with a common double lever F G moving on the center H. The piſtons in D and E both ſuck and force alternately, and are here repreſented in their different actions, as are alſo the reſpective valves at I K and L M.

The water to ſupply this engine, if there is no opportunity of putting the end of a ſucking pipe, occaſionally to be ſcrewed on, into a moat or canal (which would ſpare much hurry and labour in caſe of fire) is poured into the veſſel A B; and being ſtrained through the wire grate N is, by the preſſure of the atmoſphere, raiſed through the valves K and M into the barrels of D or E, when either of their forcers aſcend; whence again, upon their deſcent, it

will be powerfully propelled into the air-veſſel C C, through the valves I and L by turns: the common air then between the water and the top of the air-veſſel C C will from time to time be forcibly crowded into leſs room, and much compreſſed; and the air being in that condenſed ſtate poſſeſſed of a ſtrong and lively ſpring, and always endeavouring to dilate itſelf every way equally in ſuch a circumſtance, bears ſtrongly both againſt the ſides of the veſſel wherein it is confined, and the ſurface of the water thus injected; and thus produces a conſtant regular ſtream, which riſes through the metal pipe P into the leather one Q, and this latter being perfectly flexible, may be led about into rooms and entries, as the caſe may require.

Should the air contained in this veſſel be compreſſed into half the ſpace it took up in its natural ſtate, the ſpring of it will be nearly doubled; and as before it equalled and was able to ſuſtain the preſſure of the atmoſphere, ſince it has now a double force, by the power of that ſpring alone it will throw water into air of the common degree of denſity about thirty feet high. And ſhould this compreſſure be ſtill augmented, and the quantity of air, which at firſt filled the whole veſſel, be reduced into one-third of that ſpace, its ſpring will be then able to reſiſt, and conſequently to raiſe the weight of a treble atmoſphere; in which caſe it will throw up a jet of water ſixty feet high. And ſhould ſo much water again be forced into the veſſel as to fill three parts of the capacity, it will be able to throw it up about ninety feet high: and wherever

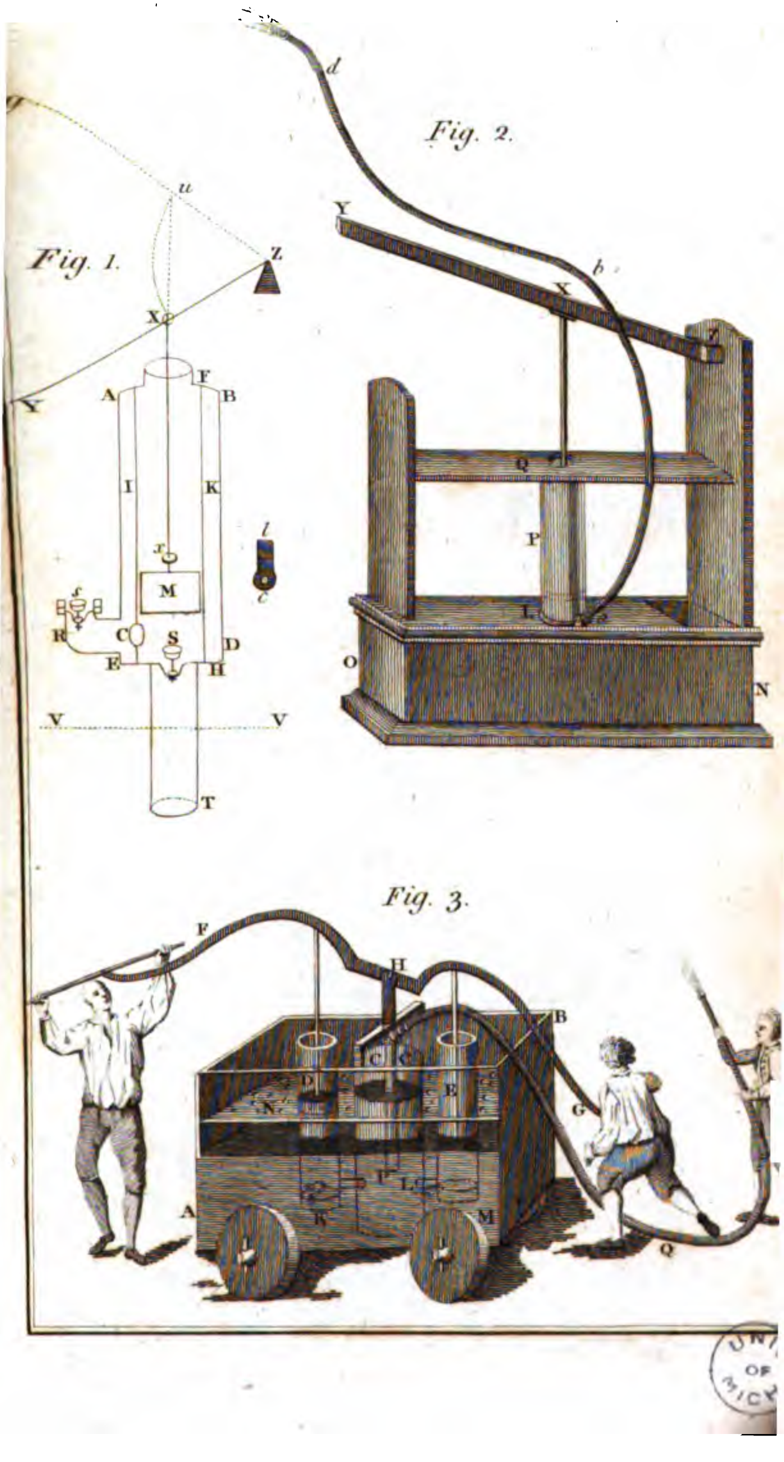
Fig. 1.
Fig. 2.
Fig. 3.

wherever the ſervice ſhall require a ſtill greater riſe of water, more water muſt be forced into this veſſel; the air therein being thus driven by force into a ſtill narrower compaſs, at each exploſion, its gradual reſtitution to its firſt dimenſions is what regularly carries on the ſtream between the ſtrokes, and renders it continual during the operation of the machine.

Various agents are employed to put pumps in action, ſuch as men, horſes, ſtreams of water, vapour, wind, &c. Small pumps, ſuch as thoſe in common wells, or fire engines, are generally wrought by men. When a conſiderable quantity of water is required to be raiſed, the moving power muſt be increaſed; and in order that a regular effort may be employed, or very nearly ſo, ſeveral additions are occaſionally made to the mechaniſm of pumps, ſo that when one ſet of piſtons deſcend another ſet may be made to riſe by the ſame force. The great engine at Marli is wrought by an apparatus of this kind.

The action of theſe engines depends upon the regularity of the alternate motion of the ſuckers or valves. It follows then, that theſe ſhould be ſo conſtructed and diſpoſed as perfectly to retain the water when they are cloſed, and to open eaſily when the action of the machine is directed to that object.

V. Of the motion of water in conduit pipes.

When it is required to conduct water from one place to another, it is very clear that the conducting pipes muſt be longer than the ſpace through which it is to be conveyed.

In treating of the discharge of water through additional pipes, I have taken but a cursory notice of the resistance by friction, because there it is scarcely perceptible; but it is not the same with respect to pipes of considerable extent; the friction of the water against their sides lessens considerably the velocity of the flowing water, as has been proved by experiments. I shall first speak of rectilinear pipes.

In the following experiments two pipes were employed, one of an inch and a quarter diameter, and the other of two inches. The two pipes were successively lengthened from thirty feet to one hundred and eighty; and the constant height of the water in the reservoir, above the pipes, was sometimes one foot, and sometimes two.

The following table shews the results of these experiments:

| The constant height of the water in the reservoir above the pipe, in inches | The distance to which the water was conveyed, expressed in feet. | The number of cubic inches of water furnished in one minute, by a pipe of an inch and a quarter diameter. | The number of cubic inches of water furnished in one minute by a pipe of two inches diameter. |
|---|---|---|---|
| 1 | 30 | 2778 | 7680 |
| 1 | 60 | 1957 | 5564 |
| 1 | 90 | 1587 | 4534 |
| 1 | 120 | 1351 | 3944 |
| 1 | 150 | 1178 | 3486 |
| 1 | 180 | 1052 | 3119 |
| 2 | 30 | 4066 | 11219 |
| 2 | 60 | 2888 | 8190 |
| 2 | 90 | 2352 | 6812 |
| 2 | 120 | 2011 | 5885 |
| 2 | 150 | 1762 | 5232 |
| 2 | 180 | 1583 | 4710 |

If,

If, by the aid of the table of additional pipes, which has been before inserted, we should wish to find the quantity of water discharged by two additional pipes of one inch and one-third and two inches diameter, under the same height of the reservoir, and without having any regard to friction, but only to the areas of the orifices of the pipes, it will be found, that during one minute,

1. The height of the reservoir being one foot, the pipe of one inch and one-third diameter, in this case there will be discharged six thousand two hundred and ninety-two cubic inches of water.

2. The height of the reservoir being two feet, the same pipe will furnish eight thousand eight hundred and ninety-three cubic inches of water.

3. The height of the reservoir being one foot, and the pipe two inches in diameter, there will be discharged fourteen thousand one hundred and fifty-six cubic inches of water.

4. The height of the reservoir being two feet, the same pipe will furnish twenty thousand and eight cubic inches of water.

It is easy to perceive, that these quantities of water are much greater than the corresponding quantities in the above table; and that the quantity furnished by each pipe diminishes, in fact, in proportion to its length, because there is then a greater surface of friction. But it must be remarked, that the diminution of the quantity of water discharged is not exactly in proportion to the length of the pipe. The discharge is indeed diminished as the pipe is made longer; but this diminution decreases

(if I may use the expression) in the progress of the current; for the first thirty feet the discharge is diminished much more than in the second thirty feet; and the third augmentation of thirty feet to the length diminishes the discharge still less than the second; and so of the rest. The result of all this is, that in common practice, where great precision is not required, it may be laid down as a rule, that the quantities of water discharged in equal times, through the same horizontal pipe, under the same height of the reservoir, and at different distances from the source or reservoir, are to each other nearly in an inverse proportion of the square roots of these distances.

It may be observed from the preceding table, that a pipe of one inch and one-third diameter furnishes less water in proportion than one of two inches diameter, under the same height of the reservoir, and of the same length. The reason of this is, because there is, relatively to the quantities of water which these pipes will contain, more surface of friction in the small pipe than in the larger one.

If the same pipe was curvilinear instead of being strait, the discharge would still be diminished from this circumstance, though not in any considerable degree; but the diminution would be still greater if the curvilinear pipe was placed in a vertical instead of a horizontal position. The diminution (small as it is) is produced by the resistance which the water meets in running against the angles of the pipe, which deprive it of a part of its velocity.

But

But if the pipe, instead of being curvilinear, was angular in several points, the diminution would be greater, and the more so in proportion as those angles should be more acute, because then the resistance to the water would be more direct. When the pipes are curved, and their curvature vertical, as in Plate X. Fig. 1. there are then declivities and ascents in which the air will lodge, and resist or even impede the course of the water. For example, let A B C D E F G be a pipe, the upper extremity of which A answers to a reservoir which supplies it with water, and the extremity G goes to furnish a fountain. The pipe being filled with nothing but air, and water being made to run from A, this water will drive the air before it, and fill the portion of the pipe A B more than the portion B C; the water having arrived at the bending C, will flow down the lower part of this bending, and will proceed to fill the bending D, leaving behind it the column of air C D, which cannot escape. The water, continuing to run, will rise from D to E, and having arrived there, it will still flow down the lower part of this declivity to fill the bent F, leaving behind it a second column of air E F, which will remain confined there, notwithstanding the pressure of the column A B; for the column of air C D cannot counterbalance the pressure of the column of water D E, any more than the column of air E F is capable of counterbalancing the column of water F I; so that though the water in the pipe A B is considerably above the level G, the water can only rise towards I, and there ceases to flow. The only remedy

remedy is, to let out the two columns of air CD and E F, by placing at the elbow of the bendings two small pipes C and E, through which the air may escape, and when the course of the water is well arranged the apertures may be closed with bungs.

VI. Of the oscillatory motion of water in a siphon.

It is well known that the duration of the oscillations of two pendulums of unequal lengths are to each other as the square roots of those lengths. The oscillatory motion of water in a siphon is of the same nature.

Suppose a siphon (Fig. 2.) composed of three branches, two verticle *l n*, *m o*, and one horizontal *n o*; suppose that the interior diameter of the siphon is equal through its whole extent; that in this siphon, the fluid, in a state of rest, occupies the space *a n o d*; then the two surfaces *a b*, *c d*, are upon a level. Suppose then, that, by some cause, the liquid is forced to descend to *g h*, in the branch *m o*, and consequently to elevate itself to *e f*, in the branch *l n*; as soon as this cause ceases to act, the fluid will be operated upon merely by the common laws of gravitation and motion. The excess of the length of the column *e n*, above that of the column *h o*, will force the fluid to descend, and that even below the level of the other, on account of the acceleration of its descent, which will cause the fluid in the other branch *m o* to rise; the fluid will then descend and ascend alternately, or in oscillations similar to those of a pendulum; and the deviation of each of these oscillations will be precisely the

the same as that of the oscillations of a pendulum half as long as the length *p q r* of the column of the fluid.

Since the oscillations of water follow the same law as those of a pendulum, it follows, that if the length of the column of water is augmented or diminished, the duration of each oscillation will be augmented or diminished.

VII. The oscillatory motion of water in waves has been compared by Sir Isaac Newton * to the oscillatory motion of water in a siphon.

Let A B C D E F (Fig. 3.) be supposed a sheet of water, the surface of which rises and falls in successive waves; let A C E be the tops of these waves, and B D F the intermediate hollows or concavities, which separate them. As the waves are formed by the successive ascent and descent of the water in such a manner that the higher parts become the lower, and so alternately and successively, and as the weight of the elevated water is the moving power which causes the lowest parts to ascend and the highest to descend, these alternate risings and fallings are considered as analogous to the oscillatory motion of water in a siphon, and they observe the same laws relative to their duration.

If there is then a pendulum, the length of which is equal to half the transversal distance that exists between the top or apex of a wave A (for example) and the cavity B, that is equal to half A *b*, the highest parts will become the lowest in the same

* Principia, lib. 2. prop. 46.

space

ſpace of time in which this pendulum vibrates, and in the ſpace of another oſcillation they will again become the higheſt. Each of theſe waves then will roll its whole courſe during the time which the pendulum takes in performing two oſcillations; and as a pendulum four times the length of the preceding, that is, the length of which is equal to the width of the wave A C, will make only one oſcillation, while the firſt makes two, it follows, that the waves perform their oſcillations in the ſame ſpace of time as a pendulum equal in length to the width of the ſame waves would perform its oſcillations. What is meant by the width of waves, is the tranſverſal ſpace A C, which is between their greateſt elevations, or the ſpace B D, which is between their greateſt concavities.

It follows from theſe premiſes, that waves, which are about three feet and three quarters of an inch wide, roll their whole width during a ſecond of time, and conſequently they roll one hundred and eighty-three feet ſix inches and five-ſixths in a minute, and in an hour eleven thouſand and fourteen feet two inches; waves four times as wide will roll this ſpace in twice the time; it follows then, that the wider or more expanded the waves are, the greater will be the ſpace which they will roll over in a given time.

But what has now been ſtated reſpecting the motion of waves, is founded upon this hypotheſis, that all the parts of the water riſe and fall in right lines; yet it muſt be obſerved, that both their riſe and fall are more frequently made in curved lines

than in ſtrait ones; ſo that the determination given above reſpecting the ſpace which waves roll over in a given time may be regarded only as an approximation to the truth.

VIII. The motion of wheels acted upon by the fall or force of water, though ſtrictly a branch of mechanics, is yet intimately connected with the ſcience of hydraulics.

The wheels of ſome water-mills are furniſhed with wings, float-boards, or ſhelves, at their circumference, with very little or no concavity; others are furniſhed with a kind of ladles or boxes, which will contain a conſiderable quantity of water. In the firſt caſe, the water acts upon the wheels principally by its ſhock or fall; in the ſecond, by its weight. I ſhall firſt ſpeak of wheels moved by the ſhocks of the water.

It has been proved by experience, that the more numerous the wings or float-boards are in proportion to the diameter of the wheel, the faſter it moves. To wheels of twenty feet diameter, there are commonly placed about forty float-boards; but a greater number, as for example forty-eight, would be ſtill more advantageous. To the wheels of thoſe mills which are raiſed upon boats or rafts in rivers, there are uſually only eight or ten floats; but theſe wheels would have more effect if they had fifteen or ſixteen.

When a wheel with wings or float-boards turns in a kind of frame or caſe, ſo as to prevent the water from falling immediately into the general current, the impulſe which it receives from the water is about one-fifth greater in proportion to the velocity

velocity of the fluid; than it would receive in an unconfined stream, because in the latter case the water which abounds is turned behind the float, and resists it; on the contrary, when the wheel moves in a frame, there is only a small quantity of water, which moves with as much velocity, or with rather more, than the float-board.

It has been proved by experience, that when this case or frame is but just wide and deep enough to admit the wheel to move freely, and the water has an opportunity of running out after having given its shock or impulse, the direct and perpendicular force against the floats of the wheel is about twice the force which the float would receive if it was plunged to the same depth in an unconfined current.

When a wheel furnished with forty-eight floats turns in a case or frame, and it is not plunged very deep in the water, its circumference will have about two-fifths of the velocity of the current, in which case the machine will produce the greatest effect.

It appears that float-boards are the most advantageous when they are placed in a direct line towards the center of the wheel; because but few of them would be required, since they would then be struck perpendicularly by the water, which produces the most powerful effect. When they incline, the shock is oblique, which diminishes the effort; yet a certain degree of inclination causes the water to rise the length of the float, and to remain there a certain time; it then acts by its gravity after having acted by its shock or fall, and the effect which results from this arrangement more

than

than compenſates for the diminution which the ſhock ſuffered from the obliquity with which the force was applied in the firſt inſtance. In general, the wheels placed in frames which have a certain declivity ſhould have their floats or buckets inclined ſo much towards the radius as to cauſe them to be ſtruck in a more perpendicular direction, that they may receive an augmentation of force from the weight of the water. The moſt advantageous inclination of the floats towards the radius appears by experience to be between twenty and thirty degrees.

A wheel placed near a reſervoir turns ſwifter than in any other place, becauſe then the whole force of the deſcending fluid is effectually applied; but if there is a neceſſity for placing it at the end of the water-courſe, at a certain diſtance from the reſervoir, the channel of the water-courſe or frame ſhould incline about the tenth part of its length, ſo that the ſloping may give to the water that degree of velocity which would otherwiſe be deſtroyed by friction; the wheel will then receive the ſame impulſe as if it was placed cloſe to the reſervoir.

Water acting by its weight produces a much greater effect than when it acts by its ſhock in falling. M. Parent, in the year 1704, and M. Pitot, in 1725, indeed demonſtrated, that a wheel (ſuppoſed to be without friction) moved by a current of water, and deſigned to elevate a portion of that water to the height of that which puts it in motion, is incapable of elevating it higher than $\frac{4}{27}$ or $\frac{1}{7}$, nearly; whereas the water acting upon the wheel by its

own

own weight would be capable of elevating to the height from which it defcended half of the water which defcended.

When, therefore, we have only a fmall quantity of water, and are obliged to hufband it well (which often happens, becaufe there are more fmall ftreams than large rivers) we fhould contrive to make this water act by its weight rather than by its fhock or impulfe; for this purpofe, inftead of having wheels with plain float-boards, they fhould be furnifhed with concave or hollow ones refembling buckets, whenever we can have a fall of more than four feet, and efpecially where there is not the neceffary quantity of water to turn a mill with wheels, furnifhed with plain float-boards.

M. Deparcieux, in the Memoirs of the French Academy of Sciences *, has proved, that the flower wheels with buckets move, the more will be their effect with an equal expence of water. He made a fmall wheel of twenty inches diameter, the circumference of which was furnifhed with forty-eight buckets. Upon the axis of this wheel were placed four cylinders of different fizes; the leaft was one inch in diameter, the next two inches, the third three inches, and the fourth was four inches in diameter. Thefe cylinders were different axes, about which a cord, which elevated a weight by means of a returning pully placed above the machine, wrapped itfelf. The axis of the wheel was fupported at each end by two rollers eafily put in

* For the year 1754, page 603 and 671.

motion;

motion; this was to diminish the friction. To the fore part of the wheel, and a little higher than its axis, was attached a small shelf, upon which was placed a vessel with a hole pierced in it on that side towards the wheel, which was filled with water. Above this vessel was placed a large bottle full of water inverted, and the neck of it was plunged a few lines in the water of the vessel, in order that the bottle should only empty itself in proportion as the water in the vessel ran through the aperture. The water in flowing fell into a channel which carried it into the buckets of the wheel. By this means he made sure of employing, at each experiment, always the same quantity of water.

The following table contains the results of the experiments made by M. Deparcieux. He sometimes elevated weights of twelve ounces, and sometimes of twenty-four ounces: the heaviest, resisting the most, compelled the wheel to turn slower. He wrapped the cords which supported the weights successively round the different cylinders, and found that the same weight resisted more in proportion as its cord was wrapped round a larger cylinder.

| Diameter of the cylinders. | Elevation of a weight of 12 ounces. | Elevation of a weight of 24 ounces. |
|---|---|---|
| 1 Inches. | $69\frac{3}{4}$ Inches. | 40 |
| 2 | $80\frac{1}{2}$ | $43\frac{1}{8}$ |
| 3 | $85\frac{1}{2}$ | $44\frac{1}{2}$ |
| 4 | $87\frac{3}{4}$ | $45\frac{1}{4}$ |

When the cord was wrapped round a larger cylinder, or the elevated weight was more considerable, the wheel turned ſlower. It appears from theſe reſults, that the ſame weight was carried ſo much higher according as its cord was wrapped round a larger cylinder. It appears alſo, that double the weight which retarded the rotation ſtill more, was carried to more than half of the height to which the ſingle weight was carried; in that caſe, therefore, the effect was greater.

It may be laid down as a principle, that water acts by its weight much more forcibly from the ſame height or fall, than by its impulſe; and that the ſlower wheels with buckets move, the greater, with the ſame expence of water, will be their effect. This augmentation of effect is cauſed by the ſame quantity of water acting longer, while the wheel moves with leſs velocity.

# CHAP. IV.

## OF THE OCEAN.

*Saltneſs of the Ocean.—Different Opinions as to the Cauſe.—Probable Reaſons why the Sea has been always ſalt.—Temperature of the Sea at different Depths.—Modes of rendering Sea-water freſh.*

THE greateſt quantities of water with which we are acquainted are by no means pure, but united with ſaline matter. The ocean is ſalt in all parts of the world; but the degree of ſaltneſs differs much in different climates, and is almoſt univerſally found to be greater in proportion as the water is taken up nearer the equator, where the heat of the ſun is greateſt, and the evaporation of the watery particles conſequently more conſiderable. When treating of ſea ſalt, the reſult of various obſervations relating to this ſubject were detailed.

The cauſe of the ſaltneſs of the ocean has been a ſubject of inveſtigation among philoſophers in almoſt all ages, but it ſtill remains in great obſcurity. There can be little doubt, that a large quantity of ſaline matter exiſted in this globe from the creation; and, at this day, we find immenſe beds of ſal gem, or common ſalt, buried in the earth, particularly near Cracow; but whether theſe collections have been derived from the ocean, and depoſited in conſequence of the evaporation of its waters in certain

circumstances, or whether the ocean was itself originally fresh, and received its salt from collections of saline matter situated at its bottom, or from that brought by the influx of rivers, cannot now be ascertained. No accurate observations on the degree of saltness of the ocean in particular latitudes were made till the present century, and it is not possible, therefore, to ascertain what was the *state* of the sea at any considerable distance of time, nor, consequently, whether its degree of saltness increases, decreases, or is stationary. From differences among aquatic animals, however, some of which seem adapted to salt water, and some to fresh, it is probable, that both these states of water existed from the creation of the world. We know it is true, that some kinds of fish, as salmon, are capable of existing both in fresh and in salt water, and that habit has a powerful influence over all animals; but this is not sufficient to refute the main fact, that some kinds of fish thrive only in salt water, others in fresh; some in standing pools, and others in rapid currents.

That excellent philosopher and chemist, to whose labours I am indebted for some of the most valuable parts of these volumes, the bishop of Landaff, has recommended a most simple and easy mode of ascertaining the saltness of the sea in any latitude; and as the language, in point of perspicuity and correctness, cannot be improved, I shall take the liberty of inserting it in his own words.

'As it is not every person who can make himself expert in the use of the common means of estimat-

ing the quantity of ſalt contained in ſea water, I will mention a method of doing it, which is ſo eaſy and ſimple, that every common ſailor may underſtand and practiſe it, and which, at the ſame time, from the trials I have made of it, ſeems to be as exact a method as any that has yet been thought of.—Take a clean towel or any other piece of cloth, dry it well in the ſun or before the fire, then weigh it accurately, and note down its weight; dip it in the ſea water, and, when taken out, wring it a little till it will not drip, when hung up to dry; weigh it in this wet ſtate, then dry it either in the ſun or at the fire, and, when it is perfectly dry, weigh it again. The exceſs of the weight of the wetted cloth above its original weight, is the weight of the ſea water imbibed by the cloth; and the exceſs of the weight of the cloth, after being dried, above its original weight, is the weight of the ſalt retained by the cloth; and by comparing this weight with the weight of the ſea water imbibed by the cloth, we obtain the proportion of ſalt contained in that ſpecies of ſea water.

'Whoever undertakes to aſcertain the quantity of ſalt, contained in ſea water, either by this or any other method, would do well to obſerve the ſtate of the weather preceding the time when the ſea water is taken out of the ſea, for the quantity of ſalt contained in the water near the ſurface may be influenced both by the antecedent moiſture and the antecedent heat of the atmoſphere *.'

Whether the ſea is ſalter or not at different

* Watſon's Chemical Eſſays, vol. ii. p. 116.

depths has not yet been aſcertained; but that its temperature varies conſiderably in proportion to the depth we have deciſive proof.

'With reſpect to the temperature,' ſays biſhop Watſon, 'of the ſea at different depths, it ſeems reaſonable enough to ſuppoſe, that in ſummer time it will be hotter at the ſurface than at any conſiderable depth below it, and that in winter it will be colder. Suppoſe a ciſtern, twelve feet in depth, to be filled with ſpring water of 48 degrees warmth, to the height of eleven feet; then, if we fill up the ciſtern to its top, by gently pouring water heated to 100 degrees upon the ſurface of the ſpring water, it may readily be underſtood, that the heat of this water will not be inſtantaneouſly communicated through the whole maſs of water in the ciſtern, but that the water will decreaſe in heat from the ſurface to the bottom of the ciſtern. On the other hand, if on the 11 feet of ſpring water heated to 48 degrees, we pour a foot of water heated only to 33 degrees, it may be expected, that the ſpring water, which is neareſt to the cold water, will be ſooner cooled by it than that which is at a greater diſtance; and on this account the water at the bottom of the ciſtern will be warmer than that in the middle or at the top. It muſt be obſerved, however, that cold water being, bulk for bulk, heavier than hot water, the water which has only 33 degrees of heat will deſcend, by its ſuperior weight, into the maſs of water contained in the ciſtern, and thus the water in the ciſtern will be cooled, not only by the bare communication of cold from the upper water, but by

by the actual mixture of that water with the rest, so that the difference between the heat of the water at the bottom and top will not be so great as it would have been if the cold water had not mixed itself with the rest. These suppositions of hot and cold water incumbent on the spring water in the cistern, are analogous to the action of the summer and winter atmospheres incumbent on the surface of the sea. No person, who has bathed in deep standing water in summer time, can have failed to observe, that the water grew colder and colder, according to the depth to which he descended. I have frequently observed, that the surface of a pool of water of two feet in depth, has in a sunny day, even in winter, been five degrees hotter than the water at its bottom.

'Mr. Wales describes the instrument he made use of for trying the temperature of the sea at different depths, in the following terms: "The apparatus for trying the heat of the sea water at different depths consisted of a square wooden tube of about 18 inches long and three inches square externally. It was fitted with a valve at the bottom, and another at the top, and had a contrivance for suspending the thermometer exactly in the middle of it. When it was used it was fastened to the deep sea line, just above the lead, so that all the way as it descended the water had a free passage through it, by means of the valves which were then both open; but the instant it began to be drawn up, both the valves closed by the pressure of the water, and of

course the thermometer was brought up in a body of water of the same temperature with that it was let down to *." With this instrument, which is much the same with one formerly described by Mr. Boyle, in his observations about the saltness of the sea, water was fetched up from different depths, and its temperature accurately noticed, in different seasons and latitudes.

'August 27, 1772, south latitude 24°. 40′. The heat of the air was 72½,—of the water at the surface 70,—of water from the depth of 80 fathoms 68 †.

'December 27, 1772, south latitude 58°. 21′. The heat of the air was 31 ,—of the water at the surface 32,—of water from the depth of 160 fathoms 33½ ‡.

'In the voyage to the high northern latitudes before mentioned, they made use of a bottle to bring up water from the bottom, which is thus described. "The bottle had a coating of wool, three inches thick, which was wrapped up in an oiled skin, and let into a leather purse, and the whole inclosed in a well-pitched canvas bag, firmly tied to the mouth of the bottle, so that not a drop of water could penetrate to its surface. A bit of lead shaped like a cone, with its base downwards,

* See Astronomical Observations made in a Voyage towards the South Pole, &c. in 1772, 1773, &c. by W. Wales. Introduction, p. 53.

† Wales' Obser. p. 206.

‡ Ibid. p. 208.

and

and a cord fixed to its ſmall end, was put into the bottle; and a piece of valve leather, with half a dozen ſlips of thin bladder, were ſtrung on the cord, which, when pulled, effectually corked the bottle on the inſide.'. I have here put down two of the experiments which were made during that voyage.

'Auguſt 4, 1773, north latitude 80°. 30′. The heat of the air was 32,—of the water at the ſurface 36,—of water fetched up from the depth of 60 fathoms under the ice 39*.

'September 4, 1773, north latitude 65°. The heat of the air was 66½,—of the water at the ſurface 55,—of water from the depth of 683 fathoms 40.

'It appears from all theſe experiments that, when the atmoſphere was hotter than the ſurface of the ſea, the ſuperficial water was hotter than that at a great depth; and when the atmoſphere was colder than the ſurface of the ſea, it is evident that the ſuperficial water was ſomewhat colder than that at a conſiderable diſtance below it: and I doubt not that this will generally be the caſe, though ſudden changes in the temperature of the atmoſphere, which cannot be inſtantly communicated to the ſea, may occaſion particular exceptions.

'In the year 1779, ſeveral experiments were made, with great accuracy, in order to inveſtigate the temperature of the lake of Geneva, and of other lakes in Switzerland, at different depths; we learn from them, that in winter time there is very little

* Voyage towards the North Pole, p. 143.

difference

difference between the heat of the water at the surface, and at a great depth below it; but that in summer, the superficial water is considerably warmer than that which is at a great distance from the surface. The experiments were made with a thermometer graduated after Reaumur's scale; some of them, reduced to Fahrenheit's scale, are expressed below.

'Temperature of the lake of Geneva at different depths, in the beginning of February 1779, after a month's uninterrupted frost.

'Heat of the open air variable from 37 to 40 degrees.

| | | |
|---|---|---|
| 'Water at the surface of the lake | | $42\frac{1}{8}$ |
| Depth 100 feet | - - | $42\frac{1}{8}$ |
| Depth 250 feet | - - | $42\frac{1}{8}$ |
| Depth 950 feet bottom | | $41\frac{27}{32}$ |

'In another part of the lake, open air from 37 to 40.

| | | |
|---|---|---|
| Surface | - - - - | $42\frac{1}{8}$ |
| Depth 350 feet | - - | $42\frac{1}{8}$ |
| Depth 620 feet, bottom | - | $41\frac{27}{32}$ |

'Temperature of the lake of Neuchâtel, July 17, 1779.

| | | |
|---|---|---|
| Air | - - - - | $75\frac{1}{5}$ |
| Surface | - - - - | $73\frac{5}{8}$ |
| Depth 225 feet, bottom | - | 41.[*] |

Sea water may be rendered fresh by freezing, which excludes or precipitates the saline particles, or by distillation, which leaves the salt in a mass at

* Watson's Chemical Essays, vol. ii. p. 129.

the bottom of the veſſel. Upon theſe principles, a mode of obtaining a ſupply of freſh water at ſea was recommended ſome years ago to the Admiralty, by Dr. Irving. It conſiſted in only adapting a tin tube of ſuitable dimenſions to the lid of the common ſhip's kettle, and condenſing the ſteam in a hogſhead which ſerved as a receiver. By this mode a ſupply of twenty-five gallons of freſh water per hour might be obtained from the kettle of one of our ſhips of war. I have not underſtood, however, that the plan has been as yet introduced into general practice.

## CHAP. V.

### OF RAIN.

*Recapitulation of Doctrines relative to spontaneous Evaporation.—Vapour by some supposed to consist of hollow Vesicles.—Rain.—Different Theories of Rain.—Snow.—Hail.—Rain which freez in coming in contact with the Earth.—Large Hail-stones.—Fogs.—Dew.—Hoar-frost.—Instances of partial freezing when the general Temperature is above the freezing Point.*

IN a preceding volume, when treating of the effects of heat or fire, and particularly of vapour, it was necessary to introduce a few observations relative to spontaneous evaporation. It is proper, however, to repeat, in this place, that philosophers are by no means agreed with respect to the cause of this phenomenon. By some it has been attributed to a solution of water in air similar to that of saline substances in water; by others, to the action of the electric fluid. The first of these opinions had till lately obtained almost universal assent, but is now relinquished, since it is found that evaporation proceeds, as well in the exhausted receiver of the air pump, as when air is present. Electricity has been found to promote evaporation, and clouds are almost universally electrical; but evaporation is carried on continually where there is no reason to suppose the presence of the electric fluid, at least where its operation cannot be discovered by any known test. It is at present commonly

monly supposed, that redundant heat is the general cause of the evaporation of water, and that it always proceeds in proportion to its temperature, compared with that of the surrounding medium.

There is one circumstance very much in favour of the opinion, that the emission of heat is the chief cause of evaporation, which is, that every liquor cools when it evaporates, because the portion of the fluid which disappears carries away a quantity of caloric from the liquor, which becomes latent in the vapour.

A doubt has arisen among philosophers, whether water, as it exists in a transparent state in the atmosphere, is in particles of an uniform density, or assumes the form of hollow vesicles, When there is a tendency to rain or snow, it is known to exist in the state of minute drops and icicles; but the solution is then not perfect, its transparency is impaired, and clouds are produced.

The existence of hollow spheres is said to have been actually observed by several persons; but as a microscope of considerable magnifying power must be employed, this may have been a source of error, and may have produced delusive appearances. The simplest and most instructive manner of observing them is to expose a cup of some warm aqueous fluid, of a dark colour, as coffee, or water mixed with ink, to the rays of the sun in a fine day, when the air is very calm; a cloud will rise from the fluid to a certain height, and then disappear. An attentive eye will soon discover that this cloud consists of small round grains, of a whitish colour, and detached

detached one from the other. To acquire a more distinct idea of their form, they may be observed, as they rise from the surface of the liquor, with a lens of about one inch and an half focus, being careful, however, to keep the lens out of the vapours, that they may not deprive it of transparency.

Spherical balls of different sizes may in this manner be observed proceeding from the surface with more or less rapidity. The more delicate rise swiftly, and soon traverse the field of the lens; the larger fall back into the cup, and, without mixing with the fluid, roll upon its surface like a light powder, which obeys every impulse of the air. The lightness of these small spheres, their whiteness, &c. give them an appearance altogether different from solid globules; their perfect resemblance to the larger balls, that are seen floating on the surface of the liquid, can leave no doubt of their nature; it is sufficient to see them to be convinced that they are hollow bubbles, like those blown from water and soap. M. Kratzenstein endeavoured to estimate their size, by comparing them with a hair, and found that they were twelve times smaller than the hair, the diameter of which was the three hundredth part of an inch, and consequently one of these was only the three thousand six hundredth part of the same measure.

These bubbles may even be sometimes, it is said, observed in a fog, or in a cloud, when the observer is situated on a hill. To this end M. de Saussure used a lens of one and an half or two inches focus,

which

which he held near his eye with one hand, in the other he held any ſmooth, flat, and poliſhed ſurface, of a black colour, as the bottom of a tortoiſe ſhell box, bringing this towards the lens till it was very near the focal diſtance; he then waited till the agitation of the air brought ſome particles of the cloud into the focus of the lens; when the cloud was thick this ſoon happened, and he perceived round and white particles, ſome paſſing with the rapidity of lightning, others moving ſlowly; ſome rolling on the ſurface of the tortoiſe ſhell, others ſtriking againſt it obliquely, and rebounding like a ball from a wall, and others fixing themſelves to it. Small drops of water might alſo be ſeen to ſettle on the tortoiſe ſhell, but they were eaſily diſtinguiſhed from the hollow ſpherules, by their tranſparency, their gravity, and their pace, Further, clouds do not form a rainbow; it is produced by ſolid drops; when a cloud is not in an actual ſtate of reſolution, it does not change the form of the ſtars which are ſeen through it; for infinitely thin meniſcuſſes do not ſenſibly change the courſe of the rays of light; but as ſoon as the cloud begins to reſolve itſelf into ſolid drops, or even without clouds, when ſolid drops begin to be formed in the air, the ſtars ſeen through them are all defined, ſurrounded with a diffuſe light, circles, and halos; hence, theſe meteors are the forerunners of rain, for rain is nothing more than theſe drops augmented or united. When the veſicular vapours are condenſed by cold, the water which formed the bubble cryſtallizes,

cryſtallizes, ſometimes into hoar froſt, ſometimes into ſnow; when it does not freeze, they unite in dew, or deſcend in rain. Many other curious properties concerning the veſicular and concrete vapours are related in M. de Sauſſure's Eſſai ſur l' Hygrometrie*.

The precipitation of water from the atmoſphere, in rain has given riſe to as much ſpeculation as evaporation; and it muſt be confeſſed, that the cauſe of neither has yet been very clearly aſcertained. By ſome it is ſuppoſed, that the capacity of the air for ſuſpending aqueous vapour is in proportion to its heat, and therefore that any circumſtance which cools the atmoſphere will produce rain. If, therefore, according to this theory, a ſtratum of cold air meets with a warmer ſtratum, a fall of rain is occaſioned, becauſe the warmer ſtratum is cooled. To this it has been replied, that by this mixture the colder ſtratum muſt be as much warmed as the warmer is cooled, and, therefore, that no precipitation ought to take place. In order to obviate this difficulty, Dr. Hutton ſuppoſes that heat enables the atmoſphere to ſuſpend water in an increaſing ratio, according to the quantity of it. Thus, if two degrees of heat enable a certain quantity of air to ſuſpend two given meaſures of water, three degrees of heat will enable the ſame quantity of air to ſuſpend more than three ſuch meaſures. Upon this ſuppoſition, if two ſtrata of air, each of which is

* See Adams's Lectures on Natural Philoſophy.

charged

charged with as much water as its temperature enables it to suspend, meet together, and are reduced to a mean temperature; they will not be able to suspend as much water as in their separate state, and a precipitation of part of the water will consequently be produced *.

Others consider rain as an electrical phenomenon†, and it is very generally allowed, that electricity at least concurs with other causes in producing it. Bodies charged with the same electricity, whether it is negative or positive, always repel each other, and the aqueous particles which compose clouds, being acted on in this way, will be prevented from uniting into drops sufficiently large to fall to the earth. The rapidity with which rain falls after a discharge of lightning from a cloud, tends much to confirm this opinion. Rain also falls heaviest from the center of a cloud, where the electric matter has been found by experiment to be generally in equilibrio; while very little is discharged from the edges, which are usually found to be electrified either positively or negatively.

The wind has been supposed to have an effect in producing rain, by driving the aqueous particles into contact, and thus causing them to unite into drops. But, by experience, wind seems to have

* That heat has a considerable influence in suspending aqueous vapour, appears from the phenomenon of dew; which, the reader will remember, is part of the water taken up by the air during the day time, but which is again deposited during the coolness of the night.

† See Book IV. chap. 6.

 the

the direct contrary influence, and frequently prevents rain.

Besides rain, many other phenomena are produced by the capacity which air has in different circumstances of taking up, suspending, and depositing water; the chief of these are snow, hail, fogs, clouds, dew, and hoar frost.

The cold of the higher regions of the atmosphere is sometimes so great, as to freeze the aqueous particles which form clouds. If the particles become frozen before they have had time to unite into drops, many of the small icicles which are produced, uniting together, and being connected only at a few points, form flocculent masses, which are called snow. The order and arrangement of the icicles is not always the same; they vary greatly, and this produces the variety which is observed in snow. It is remarkable, that though snow varies at different times, yet what falls together is always the same; that is, the snow which falls at a particular time, consists of flakes, which vary only in size, but are all formed of particles disposed in a similar manner. We are not sufficiently acquainted with the laws by which the concretion or crystallization of bodies are regulated, to explain the cause of these phenomena. On account of the small quantity of matter contained in snow, in proportion to the surfaces exposed, it meets with great resistance in passing through the atmosphere, and consequently falls very slowly. Its great surface also renders it very susceptible of evaporation, which con-

considerably diminishes its weight even in the coldest weather.

If the cold is so moderate, as to allow the particles of water to unite into drops before congelation takes place, particles of ice are produced, which are called hail. The same thing may be supposed to happen when the lower regions of the atmosphere are colder than the upper, which, though contrary to the general course of things, sometimes happens. In such a case, the aqueous particles, after having united above into rain, are congealed in their descent, and are converted into hail. In the year 1775 or 1776, rain fell at Liverpool, which became solid as soon as it reached the surface of the earth, in such a manner as to give a covering of ice to whatever was wet with it, and even to form icicles on the dress of persons exposed to it. This phenomenon I have also witnessed elsewhere.

Hail, when first formed, must be perfectly round, because formed from a fluid; and all fluids, when placed in such situations as to receive an equal pressure in every direction from the medium which surrounds them, naturally assume a spherical form. Hail, however, when it arrives at the earth is often angular; this must be explained, either by supposing that the particles have begun to dissolve, or that they were sufficiently cold to congeal and attach to their surface, the aqueous particles with which they came into contact in their fall. Hail, when first formed, is never larger than the drops of water which fall in rain; but from the cause just mentioned, hail-stones have sometimes been known

to fall as large as nuts, or even as hens' eggs. In order to convince ourſelves, that ſuch hail-ſtones owe their extraordinary ſize to the additions which they receive in falling, it is only neceſſary to examine them: they will almoſt uniformly be found to be angular, and never to have an uniform denſity from the circumference to the center, which clearly proves, that they are compoſed of different particles of ice connected together. In confirmation of the ſame opinion, it is obſerved, that the hail which falls on mountains, is ſmaller than that which deſcends in the neighbouring vallies. The ſame obſervation has been repeatedly made with reſpect to rain, by perſons in the habit of aſcending mountains, for the purpoſe of philoſophical experiment.

It ſometimes happens from the ſtate of the atmoſphere, or a concurrence of circumſtances not eaſily to be aſcertained, that a great quantity of aqueous particles are raiſed in the atmoſphere, where, being incompletely diſſolved, they form a thick vapour, which extends itſelf in the lower part of the atmoſphere; theſe particles, deſtroying the tranſparency of the atmoſphere, form fogs. Fogs are more frequent in low, wet, and marſhy ſituations, near rivers and ponds, than in ſuch parts of a country as are elevated and dry. It ſometimes happens, that certain exhalations are mixed with fogs, which are perceived by their unpleaſant ſmell, and by an acute ſenſation which is felt by the throat and eyes.

Fogs are much more frequent in cold ſeaſons,

and in cold climates, than in ſuch as are warm, becauſe in the former, the aqueous particles being condenſed almoſt as ſoon as they proceed from the ſurface of the earth, are incapable of riſing into the higher parts of the atmoſphere. If the cold is augmented, the fog freezes and attaches itſelf in ſmall icicles to the branches of trees, to the hair and clothes of perſons expoſed to it, to the blades of graſs, &c.

When fogs riſe to a conſiderable height in the atmoſphere, and are collected in a denſe ſtate, whether this happens from any action of the air or from other cauſes, they form clouds, which float in different regions of the atmoſphere according to their ſpecific gravity; ſince they neceſſarily riſe or fall, till they arrive at that part of the atmoſphere which is in equilibrium with themſelves. As the atmoſphere is heavieſt below, denſe and thick clouds, which are at the point of uniting into rain, float near the ſurface of the earth, while the fleecy and thin clouds ſoar aloft. We often obſerve both kinds at different heights in the atmoſphere at the ſame time. As clouds are formed of water, they are moſt copiouſly produced where the air has moſt opportunity of acting on that fluid. Conſequently winds which blow from the weſt and ſouthweſt, from the atlantic ocean, bring more clouds to this country than eaſterly winds, which only paſs over a narrow channel of the ſea.

During the day time the ſun heats the earth, water, air, and every thing which is expoſed to its rays. The heat communicated to all theſe bodies is diminiſhed after ſun ſet, but the air is more ſud-

denly cooled than the more ſolid bodies. Heat, therefore, which has always a diſpoſition to diſtribute itſelf equally, paſſes from the ſurface of water and earth into the air, and carries with it ſome aqueous particles, which are ſuſpended near the ſurface. When the cold increaſes during the night, theſe vapours are condenſed, and occaſion that dampneſs which is felt on the clothes of perſons expoſed to the night air, and form that dew which is ſo refreſhing to vegetables ſcorched during the day time by the ſummer's ſun.

In cold weather the dew becomes frozen into hoar froſt, for the formation of which it is not neceſſary that the earth, or even the air, ſhould be ſo far cooled as to occaſion the congelation of water into ice. This fact can only be explained, by conſidering that theſe ſmall drops of water expoſe a large ſurface to the action of the air; and by this means evaporation, which powerfully produces cold, is promoted. For the ſame reaſon clothes hung out to dry, are frequently frozen ſtiff, when no ice is formed in water expoſed to the ſame degree of cold, but in circumſtances leſs favourable to evaporation.

# CHAP. VI.

## OF SPRINGS AND RIVERS.

*Origin of Springs.—Digging of Wells.—Nature of Springs.—Marshes.—Cheap and easy Mode of draining them.—Intermitting Springs.—Rivers.—Their Source, &c.*

THE water which falls on the ſurface of the earth, in rain, ſnow, &c. penetrates its ſubſtance till it meets with a ſtratum of clay, ſtone, or ſome other matter which ſtops its deſcent; it then glides laterally on the ſtratum which ſuſtains it, and in the direction to which it leans, till meeting with an aperture, it appears on the ſurface of the earth in the form of a ſpring. As water always has a tendency to deſcend, ſprings are always lower than the ſource from which they are ſupplied; ſprings are moſt common on the ſides and at the bottom of mountains; they are ſeldom found quite at the ſummit of a mountain, and are rare where a country is every where level to a conſiderable diſtance, becauſe there the ſtrata are parallel, and do not conduct the water to any particular point. In order to obtain water, therefore, in flat countries, it is in general neceſſary to dig into the earth, when it is found to flow copiouſly from the ſides of the opening, at no great diſtance from the ſurface. When wells are dug in elevated ſituations, water is ſeldom met with till we have dug to a conſiderable depth, and got below the general level of the country.

A curious circumſtance occurs in the making of wells at Modena and Stiria in Italy. The workmen begin by digging through ſeveral ſtrata or ſoils, till they come to a very hard kind of earth much reſembling chalk; here they begin their maſon-work, and build a well, which they carry on at their leiſure till they have finiſhed it, without being interrupted with one drop of water, and without any apprehenſion of not finding it when they come to make the experiment. The well being finiſhed, they bore through the hard bed of chalk, upon which the well is built, with a long auger, but take care to get out of the well before they draw it out again; which when they have done, the water ſprings up into the well, and in a little time riſes to the brim, nay ſometimes overflows the neighbouring grounds. Now there can be little doubt, that theſe waters flow from reſervoirs which are collected within the Appennine mountains, not far from Modena, and taking their courſe through ſubterraneous paſſages, endeavour to force their aſcent to the ſame height from which they deſcend, wherever they can find a vent.

As all the water which falls in rain has undergone a natural diſtillation, it is much more pure when it firſt falls, than after it has paſſed through different ſtrata of the earth and riſes in ſprings. Spring water is always found to contain ſome foreign admixture; if this ſhould be only an earthy ſalt, the water is called hard; if it contains other ſubſtances, it then receives the denomination of mineral water; but

but theſe will require to be treated of in a diſtinct chapter.

The water which lies upon marſhes and ſwampy grounds, has generally its ſource in ſome ſpring, which is placed above the level of the marſh. The ſoil, therefore, in thoſe places, being generally of a ſpongy texture imbibes the water, and permits it to diſperſe through its whole maſs, rather than force its way through a certain aperture; and as marſh-lands are commonly level, the water will be more eaſily diffuſed through the ſoil, than it can be upon the declivity of a hill. The great art, therefore, in the draining of marſhes is to diſcover the ſource, which may be looked for on the brow of ſome eminence which overhangs them; and it may generally be found by obſerving where the boggy part grows narrow and angular, and points as to an apex, which is the ſpring whence all the miſchief proceeds. When the ſource is once diſcovered, the water may be eaſily drawn off by drains, aqueducts, or pipes, according to the circumſtances of the caſe. The common mode of draining land by cutting deep trenches, or drains, through the marſh itſelf, to ſerve as reſervoirs for the water, is much more laborious and expenſive, and indeed ſeldom anſwers the end propoſed; for as ſoon as the trenches fill, the ground is rendered as ſwampy as ever; and even where drains are made on the principle of an inclined plain to draw off the water, they are frequently ſtopped by the mud of the marſh, and the leaſt ſtoppage expoſes the land again to at leaſt a partial overflow.

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There are ſome ſprings which exhibit a very curious phenomenon, a kind of tide or intermiſſion, by which the water at certain periods appears to riſe to a conſiderable height, and gradually to ſubſide. Theſe are called intermitting ſprings. It was long imagined, that theſe fountains were repleniſhed by ſome connection with the ſea; that the water was freſhened by its progreſs through ſand and earth, and that their riſing and falling depended on the tide. It was, however, found, that the periods of the water riſing and falling in theſe ſprings, did not correſpond in point of time with the tides of the adjacent ſeas, and that the periods were different in different ſprings, contrary to the regular riſing and falling of tides in the ocean. The phenomenon has ſince been very ſatisfactorily explained, and upon a very ſimple and obvious principle. It has been already ſhewn, that when a ſiphon is inſerted in a veſſel containing water, if the air is drawn out of the ſiphon, or by any means the water is made to flow over the bent of the tube, which lies above the brim of the veſſel, the water will continue to flow over the brim through the ſiphon till the whole is exhauſted.

To account, therefore, for the intermitting ſpring, we have only to ſuppoſe, that a cavity or receptacle is formed in the bowels of the hill or mountain, where the ſpring is ſituated, which gradually fills with water like other reſervoirs; by the interpoſition of ſome ſtratum of ſtone or rock, the tube or cavity which conveys the water from this receptacle to the ſpring or mouth where it iſſues, is bent

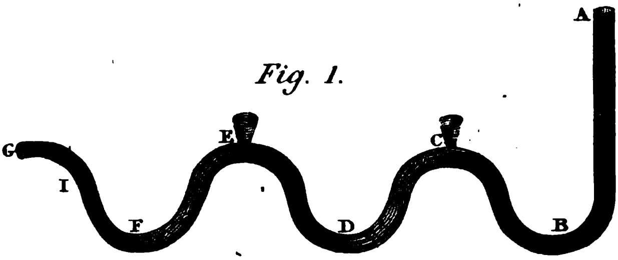


Fig. 1.

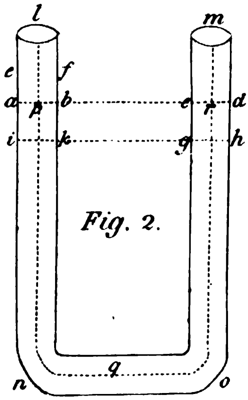


Fig. 2.

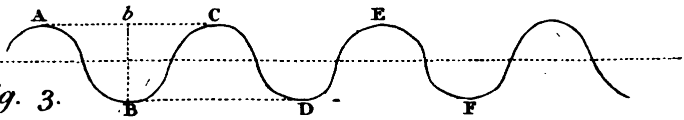


Fig. 3.

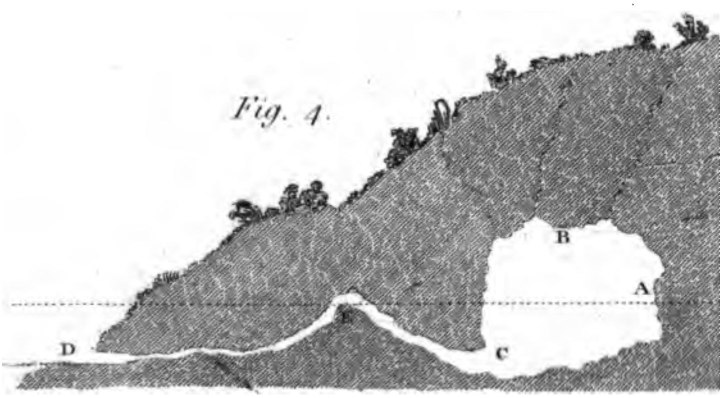


Fig. 4.

in the form of a ſiphon, the bent of which is conſiderably higher than the bottom of the reſervoir. Whenever, therefore, the reſervoir or receptacle is filled as high as the bent of the tube, the water will riſe in it to its level, and begin to flow into the ſpring, which will continue till the receptacle is exhauſted. While this proceſs is going on the water in the ſpring will riſe; and as ſoon as the receptacle is exhauſted, the water, being drawn off by a ſtream or rivulet, will appear to fall in the well of the ſpring, and will continue to fall till the receptacle is again ſupplied to the height of the ſiphon or tube, when the proceſs of filling will be again renewed.

To render the matter perfectly plain, let A B C (Plate X. Fig. 4.) repreſent the cavity or receptacle, from the bottom of which C proceeds the tube or ſiphon D E. When the water riſes in the receptacle to the level of E in the tube, it will begin to flow into the ſpring at D, on the principle explained in the preceding paragraph, and the whole phenomenon will be eaſily accounted for.

With any perſon who has carefully obſerved the courſe of rivers, and traced them to their ſources, there can be little doubt that they are formed by the confluence of ſprings, or of the little ſtreams or rivulets that iſſue from them; with perhaps the exception of thoſe rivers which proceed from lakes, where the reſervoir is ready formed, and generally by the ſame means.

In the beginning of the preſent century, the philoſophical world was agitated by a debate concerning the origin of thoſe waters which are neceſ-

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ſary for the ſupply of rivers, &c. one party contended ſtrongly for the exiſtence of a large maſs of water within the bowels of the earth, which ſupplied not only the rivers but the ocean itſelf; at the head of theſe we may place the ingenious but fanciful Burnet. The French philoſophers, on the contrary, aſſerted, that the waters of the ocean were conveyed back by ſome ſubterraneous paſſages to the land, and being filtrated in their paſſage, returned again to the ſea in the courſe of the rivers; but this opinion appears contrary to all the known principles of hydroſtatics.

In oppoſition to theſe hypotheſes, our illuſtrious countryman Halley contended that the proceſs of evaporation, and the immenſe depoſition of water in conſequence of it, was fully adequate to the whole ſupply. If, indeed, we conſider the immenſe quantity of water which is continually carried up into the atmoſphere by evaporation, as ſtated in a former chapter, and conſider that this is a proceſs which is continually going on, not only from the ocean but from the rivers themſelves, and from the whole ſurface of the earth, we ſhall ſee but little reaſon to doubt of Dr. Halley's hypotheſis, but may reaſonably conclude, that this kind of circulation is carried on through all nature, and that the ſea receives back again through the channel of the rivers, that water which it parts with to the atmoſphere.

'All rivers have their ſource either in mountains, or elevated lakes; and it is in their deſcent from theſe, that they acquire that velocity which maintains their

future

future current. At firſt their courſe is generally rapid and headlong; but it is retarded in its journey by the continual friction againſt its banks, by the many obſtacles it meets to divert its ſtream, and by the plains generally becoming more level as it approaches towards the ſea.

'Rivers, as every body has ſeen, are always broadeſt at the mouth; and grow narrower towards their ſource. But what is leſs known, and probably more deſerving curioſity, is, that they run in a more direct channel as they immediately leave their ſources; and that their ſinuoſities and turnings become more numerous as they proceed. It is a certain ſign among the ſavages of North America, that they are near the ſea, when they find the rivers winding, and every now and then changing their direction. And this is even now become an indication to the Europeans themſelves, in their journies through thoſe trackleſs foreſts. As thoſe ſinuoſities, therefore, increaſe as the river approaches the ſea, it is not to be wondered at, that they ſometimes divide, and thus diſembogue by different channels. The Danube diſembogues into the Euxine by ſeven mouths; the Nile, by the ſame number; and the Wolga, by ſeventy.

'The largeſt rivers of Europe are, firſt, the Wolga, which is about ſix hundred and fifty leagues in length, extending from Reſchow to Aſtrachan. It is remarkable of this river, that it abounds with water during the ſummer months of May and June; but all the reſt of the year is ſo ſhallow as ſcarce to cover its bottom, or allow a paſſage for loaded veſ-

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ſels that trade up its ſtream. The next in order is the Danube. The courſe of this is about four hundred and fifty leagues, from the mountains of Switzerland to the Black Sea. The Don, or Tanais, which is four hundred leagues from the ſource of that branch of it called the Soſtna, to its mouth in the Euxine Sea. In one part of its courſe it approaches near the Wolga; and Peter the Great had actually begun a canal, by which he intended joining thoſe two rivers; but this he did not live to finiſh. The Nieper, or Boryſthenes, which riſes in the middle of Muſcovy, and runs the courſe of three hundred and fifty leagues, to empty itſelf into the Black Sea. The Old Coſſacks inhabit the banks and iſlands of this river; and frequently croſs the Black Sea, to plunder the maritime places on the coaſts of Turkey. The Dwina, which takes its riſe in a province of the ſame name in Ruſſia, that runs a courſe of three hundred leagues, and diſembogues into the White Sea, a little below Archangel.

'The largeſt rivers of Aſia are, the Hohanho, in China, which is eight hundred and fifty leagues in length, computed from its ſource at Raja Ribron, to its mouth in the Gulph of Changi. The Jeniſca of Tartary, about eight hundred leagues in length, from the Lake Selinga to the Icy Sea. This river is, by ſome, ſuppoſed to ſupply moſt of that great quantity of drift wood which is ſeen floating in the ſeas, near the Artic circle. The Oby, of five hundred leagues, running from the lake of Kila into the Northern Sea. The Amour, in Eaſtern Tar-

tary,

tary, whose course is about five hundred and seventy-five leagues, from its source to its entrance into the sea of Kamtschatka. The Kiam, in China, five hundred and fifty leagues in length. The Ganges, one of the most noted rivers in the world, and about as long as the former. It rises in the mountains which separate India from Tartary; and running through the dominions of the Great Mogul, discharges itself by several mouths into the bay of Bengal. It is not only esteemed by the Indians for the depth, and pureness of its stream, but for a supposed sanctity which they believe to be in its waters. It is visited annually by several hundred thousand pilgrims, who pay their devotions to the river as to a god; for savage simplicity is always known to mistake the blessings of the deity for the deity himself. They carry their dying friends, from distant countries, to expire on its banks; and to be buried in its stream. The water is lowest in April or May; but the rains beginning to fall soon after, the flat country is overflowed for several miles, till about the end of September; the waters then begin to retire, leaving a prolific sediment behind, that enriches the soil, and, in a few days time, gives a luxuriance to vegetation, beyond what can be conceved by an European. Next to this may be reckoned the still more celebrated river Euphrates. This rises from two sources, northward of the city Erzerum, in Turcumania; and unites about three days journey below the same, whence, after performing a course of five hundred leagues, it falls into

into the Gulph of Perſia, fifty miles below the city of Baſſora in Arabia. The river Indus is extended, from its ſource to its diſcharge into the Arabian ſea, four hundred leagues.

'The largeſt rivers of Africa are, the Senegal, which runs a courſe of not leſs than eleven hundred leagues, comprehending the Niger, which ſome have ſuppoſed to fall into it. However, later accounts ſeem to affirm that the Niger is loſt in the ſands, about three hundred miles up from the weſtern coaſts of Africa. Be this as it may, the Senegal is well known to be navigable for more than three hundred leagues up the country; and how much higher it may reach is not yet diſcovered, as the dreadful fatality of the inland parts of Africa, not only deter curioſity, but even avarice, which is a much ſtronger paſſion. The celebrated river Nile is ſaid to be nine hundred and ſeventy leagues, from its ſource among the mountains of the Moon, in Upper Æthiopia, to its opening into the Mediterranean Sea. Upon its arrival in the kingdom of Upper Ægypt, it runs through a rocky channel, which ſome late travellers have miſtaken for its cataracts. In the beginning of its courſe, it receives many leſſer rivers into it; and Pliny was miſtaken, in ſaying that it received none. In the beginning alſo of its courſe, it has many windings; but, for above three hundred leagues from the ſea, runs in a direct line. Its annual overflowings ariſe from a very obvious cauſe, which is almoſt univerſal with the great rivers that take their ſource

near

near the line. The rainy ſeaſon, which is periodical in thoſe climates, floods the rivers; and as this always happens in our ſummer, ſo the Nile is at that time overflown. From theſe inundations, the inhabitants of Egypt derive happineſs and plenty; and, when the river does not arrive to its accuſtomed heights, they prepare for an indifferent harveſt. It begins to overflow about the 17th of June; it generally continues to augment for forty days, and decreaſes in about as many more. The time of increaſe and decreaſe, however, is much more inconſiderable now than it was among the ancients. Herodotus informs us, that it was an hundred days riſing, and as many falling; which ſhews that the inundation was much greater at that time than at preſent. M. Buffon * has aſcribed the preſent diminution, as well to the leſſening of the mountains of the Moon, by their ſubſtance having ſo long been waſhed down with the ſtream, as to the riſing of the earth in Egypt, that has for ſo many ages received this extraneous ſupply. But we do not find, by the buildings that have remained ſince the times of the ancients, that the earth is much raiſed ſince then. Beſides the Nile in Africa, we may reckon the Zara, and the Coanza, from the greatneſs of whoſe openings into the ſea, and the rapidity of whoſe ſtreams, we form an eſtimate of the great diſtance whence they come. Their courſes, however, are ſpent in watering deſerts and ſavage countries, whoſe poverty or fierceneſs have kept ſtrangers away.

* Buffon, vol. ii. p. 82.

'But of all parts of the world, America, as it exhibits the most lofty mountains, so also it supplies the largest rivers. The principal of these is the great river Amazons, which, from its source in the lake of Lauricocha, to its discharge into the Western Ocean, performs a course of more than twelve hundred leagues *. The breadth and depth of this river is answerable to its vast length; and, where its width is most contracted, its depth is augmented in proportion. So great is the body of its waters, that other rivers, though before the objects of admiration, are lost in its bosom. It proceeds after their junction, with its usual appearance, without any visible change in its breadth or rapidity; and, if we may so express it, remains great without ostentation. In some places it displays its whole magnificence, dividing into several large branches, and encompassing a multitude of islands; and, at length, discharging itself into the ocean, by a channel of an hundred and fifty miles broad. Another river, that may almost rival the former, is the St. Lawrence, in Canada, which rising in the lake Affiniboils, passes from one lake to another, from Christinaux to Alempigo; and thence to lake Superior; thence to the lake Hurons; to lake Erie; to lake Ontario; and, at last, after a course of nine hundred leagues, pours their collected waters into the Atlantic ocean. The river Mississippi is more than seven hundred leagues in length, beginning at its source near the lake Affiniboils, and ending at its opening into the Gulph of Mexi-

* Ulloa, vol. i. p. 388.

co.

co. The river Plata runs a length of more than eight hundred leagues from its ſource in the river Parana, to its mouth. The river Oroonoko is ſeven hundred and fifty leagues in length, from its ſource near Paſto, to its diſcharge into the Atlantic ocean.

'Such is the amazing length of the greateſt rivers; and even in ſome of theſe, the moſt remote ſources very probably yet continue unknown. In fact, if we conſider the number of rivers which they receive, and the little acquaintance we have with the regions through which they run, it is not to be wondered at that geographers are divided concerning the ſources of moſt of them. As among a number of roots by which nouriſhment is conveyed to a ſtately tree, it is difficult to determine preciſely that by which the tree is chiefly ſupplied; ſo among the many branches of a great river, it is equally difficult to tell which is the original. Hence it may eaſily happen, that a ſimilar branch is taken for the capital ſtream; and its runnings are purſued, and delineated, in prejudice of ſome other branch that better deſerved the name and the deſcription. In this manner *, in Europe, the Danube is known to receive thirty leſſer rivers; the Wolga thirty-two or thirty-three. In Aſia, the Hohanno receives thirty-five; the Jeniſca above ſixty; the Oby as many; the Amour about forty; the Nanquin receives thirty rivers; the Ganges twenty; and the Euphrates about eleven. In Africa, the Senegal receives more than twenty rivers; the Nile receives not one for five hundred leagues upwards,

* Buffon, vol. ii. p. 74.

and then only twelve or thirteen. In America, the river Amazons receives above ſixty, and thoſe very conſiderable; the river St. Lawrence about forty, counting thoſe which fall into its lakes; the Miſſiſſippi receives forty; and the river Plata above fifty *.'

The inundations of the Ganges and the Nile have been already mentioned, and it might be added, that almoſt all great rivers have their periodical inundations from ſimilar cauſes. The author already quoted obſerves, that, 'beſides theſe annually periodical inundations, there are many rivers that overflow at much ſhorter intervals. Thus moſt of thoſe in Peru and Chili have ſcarce any motion by night; but upon the appearance of the morning ſun they reſume their former rapidity: this proceeds from the mountain ſnows, which, melting with the heat, encreaſe the ſtream, and continue to drive on the current while the ſun continues to diſſolve them.'

There are ſome rivers which are ſaid to loſe themſelves in chaſms under the earth, and to flow for ſeveral miles in ſecret and undiſcovered channels. On this circumſtance is founded one of the moſt beautiful fables of antiquity, relative to the fountain of Arethuſa, in Sicily. The ſame thing is affirmed of the Rhine, and even of the river Mole, in Surrey, which, from this circumſtance, derives its name. With reſpect to the two latter rivers, however, ſome doubts are entertained of the fact, but theſe are rather a ſubject of inquiry to the geographer than to the natural hiſtorian.

* Goldſmith's Earth, p. 200.

CHAP.

# CHAP. VII.

## HOT SPRINGS.

*Probable Causes of these Phenomena.—Abound most in volcanic Regions.—Hot Springs in Iceland, near Mount Hecla.—At Geyser.—In the Island of Ischia.—At Viterbo.—Explanation of these Phenomena.—Burning Well in Lancashire.—Explained.*

THERE are few objects in natural history, which present themselves to our considera- tion, accompanied with greater difficulties than those tepid springs, which exist in different parts of the world, of different degrees of temperature, and exhibiting a variety of the most curious phenomena. Many of these have existed as long as the earliest records, and for whole centuries have exhibited little variation in their temperature.

If any circumstance could serve to support the very dubious hypothesis of an immense reservoir of fire in the center of the earth, it would be these phenomena; yet there is but little reason to suppose that the origin of these tepid springs lies at any vast depth beneath the surface; and, indeed, if we admit the notion of a central fire, its effect ought to be more general than it is found to be. The most probable hypothesis is, therefore, that the same causes operate to produce these, which produce volcanoes; and the only inference to be drawn from their permanent temperature is, that the masses of matter, which produce volcanic eruptions, may

exiſt for a long ſeries of time, even in a ſtate of inflammation, without burſting thoſe bandages with which nature has confined them; and that heat may long be continued to a conſiderable degree in the earth, without exhibiting to our affrighted ſenſes the formidable phenomenon of a volcanic fire.

It is, however, in volcanic regions, that tepid waters are found in the greateſt quantity; and it is in theſe that they diſplay the moſt ſtriking phenomena. At Laugervarm, a ſmall lake, two days journey from Mount Hecla, in Iceland, there are hot ſpouting ſprings, one of which throws up a column of water to the height of twenty-four feet. A piece of mutton and ſome ſalmon trout were almoſt boiled to pieces, in ſix minutes, in one of theſe ſprings. At Geyſer, in the ſame iſland, there are forty or fifty ſpouting ſprings within the compaſs of three miles; in ſome the water is impregnated with clay, and white in its appearance; in ſome, where it paſſes through a fine ochre, it is red as ſcarlet; in ſome it ſpouts forth in a continued ſtream; in others, at intervals, like an artificial jet d'eau. The largeſt which Von Troil obſerved had an aperture nineteen feet in diameter, through which the water ſpouted, at intervals, nine or ten times a day; round the top of it is a baſon, which, together with the pipe, is in the form of a caldron; the margin of the baſon is nine feet higher than the conduit, and its diameter fifty-ſix feet. The water was thrown up in an immenſe column, at different times, to the height of from thirty to ſixty feet, and at one time to the height of

ninety-

ninety-two feet. Previous to this explosion the earth began to tremble in three different places, and a noise was heard like a battery of cannon *.

Another writer states, that at Geyser, in Iceland, there springs up a hot water, which, upon cooling, deposits siliceous earth; and that of this very matter it has formed for itself a crater, in which columns of water, of a stupendous bulk, after they have been thrown to the height of ninety feet and upwards, fall, and are again received. The heat of the water during the explosion cannot be measured; but after it has risen and fallen through a stratum of air ninety feet thick, it raises the thermometer to 212°, which evinces that the heat in the bowels of the earth must be much more intense; and at this we shall cease to wonder when we consider, that in this case the subterraneous fire acts upon the water in caverns, closed up by very thick strata of stones, an apparatus far more effective than Papin's digester. The crater was at first undoubtedly formed, and is daily strengthened by siliceous earth, which quits the menstruum on its being cooled, falls down, and, being in somewhat like a soft state, concretes †.

About sixty yards from the shore of the island of Ischia, at a place called St. Angelo, a column of boiling water bubbles on the surface of the sea with great force, and communicates its heat to the

* Von Troil's Letters on Iceland.

† Bergman's Differt. 13.

water of the ſea near it. It boils winter and ſummer, and is of great uſe to the inhabitants in bending their planks for ſhip-building, &c. The fiſhermen alſo frequently employ this curious caldron to boil their fiſh. Near the ſhore of this iſland Sir William Hamilton found, when bathing in the ſea, many ſpots where the ſand was ſo intenſely hot under his feet as to oblige him haſtily to retire.

There is alſo a boiling ſpring near Viterbo, in the Roman ſtate, called the Bullicame. It is a circular pool of about ſixty feet in diameter, and exceedingly deep, the water of which is conſtantly boiling. It is ſituated in a plain ſurrounded by volcanic mountains. A ſtony concretion floats on the ſurface of the pool, which, being carried off by the ſuperfluous water, is depoſited, and is conſtantly forming a labes or tufa, of which the ſoil all around the pool is compoſed.

Theſe fountains are beſt accounted for by ſuppoſing the pipe or conduit to communicate with a large reſervoir of water, which, being ſubject to the heat of a volcanic fire, the ſteam generated in the reſervoir by the boiling of the water acts forcibly on the water in the ſhaft or pipe, and ejects it by its elaſtic force in the form of a fountain, which will act with more or leſs vigour according to the degree of heat, and according to the reſiſtance which the water encounters in its paſſage.

The moſt ſingular circumſtance is the number of theſe ſprings which are found in almoſt every country; and even in thoſe countries which have long ceaſed to be volcanic. England itſelf has its tepid

tepid ſprings, and thoſe of Bath, Buxton, &c. are well known. Cambden mentions a well, near Wigan, in Lancaſhire, which was called the burning well. If a candle was applied to its ſurface, he ſays, a flame was excited like that of ardent ſpirits ſet on fire, and the heat and inflammation thus excited would continue ſometimes for the ſpace of a whole day, and was ſufficient to boil eggs, and even meat. As I recollect, Cambden mentions the well as having loſt its inflammable property in his time; but he notices two others of a ſimilar deſcription, one in the ſame neighbourhood, and another in Shropſhire. I have never myſelf witneſſed a ſimilar phenomenon, nor do I know of any ſuch that exiſts at preſent, at leaſt in Britain.

Should, however, the fact be as it is related by Cambden, the reader, after what has been ſtated in a preceding chapter, will not find it difficult to explain the cauſe. The country where the well is, or was ſituated, abounds in coals. The well is therefore impregnated with naphta, or ſome bituminous vapour; this, upon the application of an ignited body, is capable of inflammation, and can even communicate a conſiderable portion of heat to the water of the well itſelf. There is no proof, however, that the Bath or Buxton waters are impregnated with any bituminous matter, though coals are plentiful in the neighbourhood; and as theſe waters contain a ſmall portion of iron, there is reaſon to ſuppoſe them connected with beds of pyrites, or poſſibly with a latent ſubterraneous fire.

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On the whole, we are not sufficiently acquainted with the internal parts of the earth to account satisfactorily for these and other phenomena of a similar kind, and whatever is advanced in the way of theory on these topics should be advanced with becoming diffidence, and rather with a view of exciting the attention and curiosity of others, than for the purpose of establishing a system unsanctioned by experiment, or building a reputation on the fallible basis of mere hypothesis.

CHAP.

# CHAP. VIII.

## MINERAL WATERS.

*Capacity of Water as a Solvent.—Substances commonly found in Mineral Waters.—Fixed Air.—Mineral Acids.—Alkaline Salts.—Neutral Salts.—Earthy Substances.—Sulphur.—Metals.—Mode of examining and analizing Mineral Waters.—Chemical Tests.—Analysis of the most celebrated Mineral or Spa Waters.—Aix-la-Chapelle.—Bath.—Bristol.—Buxton.—Cheltenham.—Epsom.—Harrowgate.—Matlock.—Pyrmont.—Scarborough.—Spa.—Reflections on the Use of Mineral Water in general.*

THE capacity which water has of holding a variety of ſubſtances in ſolution has been frequently mentioned in the courſe of theſe volumes, and indeed is a fact ſo well known and underſtood, that to inſiſt much upon it would be uſeleſs and even impertinent.

It was alſo intimated, that the water of ſprings receives the name of mineral water from the foreign ſubſtances which are contained in it. Theſe ſubſtances are various, and more than one is commonly found in mineral waters; but in general they may be referred to the following heads:

1. Fixed air, or carbonic acid gas. This ingredient occaſions an appearance of briſkneſs in water, ſimilar to that of fermenting liquors, which is chiefly obſervable when the water is poured from one veſſel into another. It is very volatile, and ſoon eſcapes on the water being expoſed to the air. This ingredient

ingredient frequently occaſions giddineſs in perſons who are not accuſtomed to it. An artificial water of this kind may be prepared at any time by impregnating water with fixed air.

2. The vitriolic, nitrous, and muriatic acids. One or other of theſe acids exiſt in almoſt all mineral waters; they are uſually combined with earthy or metallic baſes, but ſometimes, eſpecially the vitriolic, exiſt in a ſeparate ſtate, ſo as to occaſion a ſenſible acidity.

3. An alkaline ſalt is found in many waters in Hungary, Tripoli, and other countries. It is uſually the foſſil alkali which is combined with fixed air in the Seltzer waters, and with the mineral acids in a great variety of others. The vegetable and volatile alkalies rarely or never are ingredients in mineral waters.

4. Neutral ſalts are not uncommon in ſprings. Common ſalt, nitre, and vitriolated magneſia, are the moſt uſual; the latter is very abundant in a ſpring at Epſom, in Surrey, and has therefore obtained the name of Epſom ſalt. Sal amoniac has alſo been found in ſome ſprings in the neighbourhood of volcanoes and burning coal mines.

5. Earthy ſubſtances. Of theſe the calcareous is ſometimes found to abound ſo much, as to be depoſited on ſuch ſubſtances as it comes in contact with, and occaſion petrifaction. In this caſe the ſuſpenſion of the calcareous earth ſeems to depend on the preſence of fixed air, which, making its eſcape when the water iſſues into the open air, ſuffers the calcareous earth to ſeparate. The calca-

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reous earth of waters is very commonly united with the vitriolic acid, and exifts in the form of gypfum, which is only foluble in water in the proportion of one part in feven or eight hundred. Calcareous nitre and muriated calcareous earth are alfo occafionally found in fprings.

6. Sulphur. Many waters feem by their offenfive fmell to contain fulphur, though very few of them, upon more accurate examination, are found to afford it. The waters generally called fulphureous or hepatic, are only impregnated with fulphureous or hepatic gas, which is a folution of fulphur in inflammable air. This is the fame gas which rifes from liver of fulphur, and liver of fulphur itfelf has been detected in a very minute quantity in mineral waters. Sometimes bitumens are met with in mineral waters, and commonly make their appearance on the furface.

7. Metals. Of thefe iron is moft frequently found in water, fometimes copper, and more rarely zinc. Waters which contain iron are called chalybeates, and are very common.

It was formerly imagined that iron was fufpended in mineral waters by means of the vitriolic acid; but M. Monnet has afcertained, that very few of them contain vitriolic acid, and that the carbonic acid, or fixed air, is almoft the only medium by which the iron is fufpended. The carbonic acid is fometimes in excefs, fo as to render the chalybeate water acidulous, in other inftances it fufpends the iron without being in excefs. Chalybeates may, in general, be known by the yellow ochry fediment depofited

poſited in their courſe, and alſo by ſtriking a purple colour with decoction of galls.

In examining any mineral waters, the firſt object of attention is, to have the water as freſh as poſſible, ſince, if it contains any volatile matters, they will ſoon fly off. A great number of trials are therefore to be made on the ſpot. The contents of the neighbouring ſtrata, particularly of any *high* ground, from which the water ſeems to proceed, are alſo to be regarded, as they often ſerve to account for the properties of mineral waters.

One of the moſt obvious circumſtances to be attended to is the degree of the heat of the *water*, and for this purpoſe it is neceſſary to be provided with an accurate thermometer. There are many ſprings which have a temperature a little above the medium temperature of the atmoſphere, though this may not be ſo remarkable as to have obtained them the name of hot ſprings. The middle temperature of theſe ſprings is found to be about forty-eight degrees, but on elevated ſituations it is leſs, in proportion to their height above the ſea. It may alſo be proper to compare the temperature of theſe mineral ſprings with that of ſome common ſprings in the neighbourhood. The ſenſible qualities, as the colour, taſte, and ſmell, are to be obſerved. In order to diſcover whether any elaſtic fluid eſcapes from it, and of what nature it is, let ſome of the water be put into a bottle, and a bladder tied about its neck. The air which eſcapes may be ſubmitted to examination. In order to obtain it, it is only neceſſary to tie another ſtring above the bottle, and then to cut between them, ſo as to ſeparate the blad-

der, which may be plunged in water or mercury, and its contents received in the pneumatic apparatus. In order to ſeparate all the air from water, it muſt be heated nearly to its boiling point, which may eaſily be done by immerſing it in a veſſel of boiling water, while it is contained in the bottle to which the bladder is annexed. The elaſtic fluids, which may be ſeparated from mineral waters, are chiefly two, carbonic acid gas, and ſulphureous gas. It is proper to obſerve the changes which are ſpontaneouſly produced on mineral waters by different degrees of heat. If any matter is depoſited during the evaporation of the mineral water, it muſt be collected for further examination.

With reſpect to the addition of certain foreign ſubſtances called re-agents, to diſcover the contents of mineral waters, it may in general be remarked, that this mode is leſs certain than evaporation; the latter method, however, is not free from objections, as the application of heat to any body not unfrequently deranges the previous ſtate of combination among its component principles. The chemical teſts beſt adapted to the diſcovery of the contents of mineral waters are the following: lime, volatile alkali, fixed alkalies, vitriolic acid, tincture of turnſole, muriated barytes, acid of ſugar, arſenic, Pruſſian alkali, and the nitrous ſolutions of ſilver and mercury. When it it propoſed to diſcover the contents of a mineral water, it is beſt to begin with ſuch teſts as are leaſt capable of altering it, and afterwards, having obſerved their effects, to proceed to complete the analyſis by teſts which have a more extenſive influence. Lime water ſeizes the carbo-

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nic acid, and forms a precipitate of chalk; it also precipitates salts with the basis of clay and magnesia, as well as the metallic salts. If after mixing an equal quantity of lime water with a mineral water, no precipitation takes place in twenty-four hours, it may be concluded, that it contains neither carbonic acid at liberty, nor a combination of that acid with fixed alkali, nor earthy salts with the basis of aluminous earth or magnesia, nor any metallic salt. But if a precipitation takes place on the addition of lime water, the next step is to examine the properties of the precipitated matter; if it has the properties of chalk, such as insipidity, the producing of an effervescence with vitriolic acid, and forming with it a compound nearly insoluble in water, that is gypsum, it must be concluded that the water contained carbonic acid, which, uniting with the lime of the lime water, produced chalk. If, on the contrary, the precipitated matter is small in quantity, and subsides very slowly; if it does not effervesce, and affords with the vitriolic acid a styptic salt, it may be concluded that it is alum, and that the mineral water contained clay: If a bitter and very soluble salt is formed on the addition of the vitriolic acid, it is the Epsom salt, and the water contained the earth of magnesia. If the addition of vitriolic acid to the precipitate produces sal martis, the water held iron in solution.

The addition of caustic volatile alkali will act like lime water, except that it will not produce a precipitation from the presence of uncombined carbonic acid in the water; the compound formed by volatile

latile alkali with that acid not being insoluble, like the chalk formed by the union of carbonic acid with lime. But besides the aluminous, the magnesian, and the metallic salts, the caustic volatile alkali will decompose those which have lime for their basis, and thus we advance one step further in the analysis of the water. The Prussian alkali precipitates the combinations of carbonic and vitriolic acid with chalk. The nitrous solutions of silver and mercury decompose all the muriatic and vitriolic salts, which may be various both in quantity and in kind. In these cases the muriatic or vitriolic acid contained in the mineral water, seizes the silver or the mercury, and forming with it an insoluble compound, falls to the bottom in a thick cloud, while the nitrous acid unites with the basis which is deserted by one or both of the other acids. It is not necessary in this place to enter into a minute detail of the methods of distinguishing the difference of the precipitates, according as the muriatic or vitriolic acid was concerned in their production, but I shall refer the reader for information on this point to what was stated when treating of the combinations of silver and mercury with the different mineral acids.

By tincture of turnsole the predominance either of an alkali or an acid is discovered: as vegetable blues are turned red by acids, and green by alkalies. Acid of sugar is a very sensible test of lime, when combined with the sparry or acetous acids. A solution of arsenic in the marine acid will precipitate sulphur from water, in which it is held dis-

ſolved by means of carbonic acid. It may be added, that white arſenic becomes yellow if immerſed in water containing hepatic gas; and a piece of poliſhed iron will receive a copper-colour from water in which copper is diſſolved. If a mineral water is found to contain a fixed alkali, it may be determined whether it is the vegetable or mineral alkali by means of vinegar. With vegetable alkali vinegar yields a deliqueſcent ſalt; with the mineral, foliated cryſtals.

It may be proper briefly to notice the compoſition and obvious properties of ſome of the moſt celebrated mineral waters, and the diſorders in which they are ſuppoſed to have moſt efficacy.

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'Aix-la-Chapelle.—This place has long been famous for its hot ſulphureous waters and baths. They ariſe from ſeveral ſources, which ſupply eight baths conſtructed in different parts of the town. Theſe waters near the ſources are clear and pellucid, and have a ſtrong ſulphureous ſmell reſembling the waſhings of a foul gun; but they loſe this ſmell by expoſure to air. Their taſte is ſaline, bitter, and urinous. They do not contain iron. They are alſo neutral near the fountain, but afterwards are manifeſtly, and pretty ſtrongly alkaline, inſomuch that cloaths may be waſhed with them without ſoap. The gallon contains about two ſcruples of ſea ſalt, the ſame quantity of chalk, and a dram and half of natron. They are at firſt nauſeous and harſh, but by habit become familiar and agreeable. At firſt drinking alſo they generally

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affect the head. Their general operation is cathartic and diuretic, without griping or diminution of strength; and they alſo promote perſpiration. The quantity to be drunk as an alterative, is to be varied according to the conſtitution, and other circumſtances of the patient. In general, it is beſt to begin with a quarter, or half a pint in the morning, and increaſe the doſe afterwards to pints, as may be found convenient. The water is beſt drunk at the fountain. When it is required to purge, it ſhould be drunk in large and often repeated draughts *.'

The heat of the different baths of the Aix-la-Chapelle waters varies from one hundred and ſix of Farenheit's thermometer to one hundred and thirty. In bathing it is proper to begin with the moſt temperate.

'BATH has long been famous for its warm chalybeate waters. There are ſeveral ſprings, but their waters are all of the ſame nature. There are ſix baths; but the principal are the *King*'s bath, the *Queen*'s bath, and the *Croſs* bath. The others are only appendages to theſe. The two former raiſe the thermometer to 116°, the latter to 112°. The water when viewed in the baths has a greeniſh, or ſea colour: but in a phial it appears quite tranſparent and colourleſs, and it ſparkles in the glaſs. It has a very ſlight ſaline, bitteriſh, and chalybeate taſte, which is not diſagreeable, and ſometimes ſomewhat of a ſulphureous ſmell; but this latter

* Elliot on Min. Waters, p. 119, &c.

is not usually perceptible, except when the baths are filling. The gallon of Bath water contains twenty-three grains of chalk, the same quantity of muriat of magnesia, thirty-eight of sea salt, and 8. 1 of aerated iron. As it rises from the pump, it contains fixed air, or other volatile acid, in a sufficient quantity to curdle milk and act upon iron. The Bath water operates powerfully as a diuretic, and promotes perspiration. If drunk quickly, in large draughts, it sometimes purges; but if taken slowly and in small quantity, it rather has the contrary effect. An heaviness of the head, and inclination to sleep, are often felt on first drinking it *.'

This water when taken inwardly is said to give a stimulus and vigour to the whole constitution, it therefore proves useful in old rheumatic complaints, and in cases of gout connected with much debility. During the use of the Bath water, and some time previous to it, the patient should live on a light diet, easy of digestion. The course should be continued for a month or six weeks. In local complaints, as in stiff joints and chronic pains, the application of the water by pumping is more efficacious than bathing the whole body.

Bristol, ' The springs are known by the name of the *Hot Wells*. The water at its origin is warm, clear, pellucid and sparkling; and if let stand in a glass, covers its inside with small air-bubbles. It has no smell, and is soft and agreeable to the taste. It raises the thermometer from about seventy to eighty

* Elliot on Min. Waters, p. 134, &c.

degrees.

degrees. It contains $12\frac{3}{4}$ grains of chalk, $5\frac{3}{4}$ of muriat of magneſia, and $6\frac{1}{2}$ of ſea ſalt in the gallon*.'

The Briſtol waters are particularly recommended in pulmonary complaints; the fame, however, of Briſtol has probably been more owing to the mildneſs of the air in that part of England, than to the virtues of its waters.

Buxton.—' This is a hot water, reſembling that of *Briſtol.* It raiſes the thermometer to 81° or 82°. It has a ſweet and pleaſant taſte. It contains a little calcareous earth, together with a ſmall quantity of ſea ſalt, and an inconſiderable portion of a cathartic ſalt. Iron has been diſcovered in it, but in ſo extremely ſmall a quantity as not to deſerve notice: and even that perhaps owing to accident. This water taken inwardly is eſteemed good in the diabetes; in bloody urine; in the bilious cholic; in loſs of appetite, and coldneſs of the ſtomach; in inward bleedings; in atrophy; in contraction of the veſſels and limbs, eſpecially from age; in cramps and convulſions; in the dry aſthma without a fever; and alſo in barrenneſs. Inwardly and outwardly it is ſaid to be good in rheumatic and ſcorbutic complaints; in the gout; in inflammation of the liver and kidnies, and in conſumptions of the lungs; alſo in old ſtrains; in hard callous tumours; in withered and contracted limbs; in the itch, ſcabs, nodes, chalky ſwellings, ring-worms, and other ſimilar complaints. Beſides the hot water, there is

* Elliot on Min. Waters, p. 145, &c.

alſo a cold *chalybeate* water, with a rough irony taſte. It reſembles the *Cawthorp* water*.'

'CHELTENHAM, *in Glouceſterſhire*, is one of the beſt and moſt noted cathartic chalybeate waters in England, though it is not ſo much frequented as formerly. The gallon contains eight drams of a cathartic ſalt, partly vitriolated natron, partly vitriolated magneſia; twenty-five grains of magneſia, part of which is united with marine, part with aerial acid; and nearly five grains of iron combined with aerial acid. It alſo yielded thirty-two ounce meaſures of air, twenty-four of which were fixed air, the reſt azotic with a portion of hepatic air. The *doſe* is from one pint to three or four. It operates with great eaſe, and is never attended with gripings, teneſmus, &c. It is beſt taken a little warm. It alſo creates an appetite; is excellent in ſcorbutic complaints, and has been uſed with ſucceſs in the gravel. As the ſpring has been calculated to yield only thirty-five pints of water an hour, without frugal management there would not be enough to ſupply the demands of the drinkers. The Walton water has lately been recommended as a ſubſtitute to obviate this inconvenience.'

EPSOM, *in Surry*.—The water has a ſlight ſaline taſte, is clear, and without ſmell. But if it is kept in covered veſſels for ſome weeks in the ſummer it will ſtink, and acquire a nauſeous and ſaltiſh bitter taſte. This was the firſt water from which the ſalt thence called *Epſom ſalt* was obtained. But the ſalt uſually ſold by that name is different from that yielded

* Elliot on Min. Waters, p. 151, &c.

by

by the Epſom water, though perhaps not inferior in virtue. It is made from the bittern left after the cryſtallization of common ſalt from ſea water. The Epſom water is cathartic; for which purpoſe it muſt be drunk to the quantity of two or three pints. It is alſo diuretic.

HARROWGATE.—'There are four ſprings at this place, but the waters of all of them are nearly alike, except in the quantity of the ſaline matter they contain. Of the three old ſprings, the higheſt gave three ounces of ſolid matter; the loweſt, an ounce and an half; and the middle one, only half an ounce. Of the latter one hundred and forty grains were earth. The water as it ſprings up is clear and ſparkling, and throws up a quantity of air-bubbles. It has a ſtrong ſmell of ſulphur, and is ſuppoſed to be the ſtrongeſt ſulphureous water in England. It has a ſalt taſte, as it contains a conſiderable quantity of ſea ſalt, together with a little marine ſalt of magneſia, and calcareous earth *.'

Harrowgate water is cathartic when taken in doſes of ſeveral pints. When uſed externally as a fomentation, it is ſaid to be uſeful in ſome diſorders of the ſkin; and by ſome phyſicians it is conſidered as efficaceous in deſtroying worms.

MATLOCK.—'At this place (which is perfectly romantic) are ſeveral ſprings of warm water, which appear to be of the nature of the *Briſtol* water, except that it is very ſlightly impregnated with iron. Its heat is about 69°, and its virtues are ſimilar to thoſe

* Elliot, p. 177 and 184.

those of the *Bristol* and *Buxton* waters. The baths are recommended in rheumatic complaints, in cutaneous disorders, and in other cases where warm bathing is serviceable. There are great numbers of petrifactions in the course of this water *.'

Pyrmont, *in Westphalia.*—' This is a very brisk chalybeate, abounding in fixed air; and when taken up from the fountain, sparkles like the briskest Champaign wine. It has a fine, pleasant, vinous taste, and a somewhat sulphureous smell. It is perfectly clear, and bears carriage better than the *Spa* water. A gallon of it contains 46 grains of chalk, 15.6 of magnesia, 30 of vitriolated magnesia, 10 of sea salt, and 2.6 of aerated iron †. Persons who drink it at the well, are affected with a kind of giddiness or intoxication; owing, it may be supposed, to the quantity of fixed air with which the water abounds. The common operation of this water is diuretic; but it is also gently sudorific; and if taken in large quantity proves cathartic. When, however, it is required to have this latter effect, it is useful to mix some salts with the first glasses. It is drunk by glassfuls in the morning, to the quantity of from one to five or six pints, according to circumstances, walking about between each glass ‡.'

* Elliot, p. 210.

† Dr. Marcard, in his *Description of Pyrmont*, on the authority of M. Westrumb of Hammeln, estimates the iron at somewhat more than eight grains to the gallon.

‡ Elliot, p. 226.

Pyrmont waters are recommended in debilitated and relaxed constitutions, attended with indigestion, low spirits, and want of appetite.

Scarborough, *in Yorkshire.*—'The waters of this place are chalybeate and cathartic; and they are more frequented and used than any other water of this class in England. There are two wells; the one more cathartic, the other a stronger chalybeate. Hence the latter (which is nearest the town) has been called the *chalybeate* spring, the other the purging; though they are both impregnated with the same principles, but in different proportions. The purging is the most famed, and is that which is usually called the *Scarborough* water. This contains fifty-two grains of calcareous earth, two of ochre, and two hundred and sixty-six of vitriolated magnesia, in the gallon: the chalybeate, seventy grains of calcareous earth, one hundred and thirty-nine of vitriolated magnesia, and eleven of sea salt. When these waters are poured out of one glass into another, they throw up a number of air-bubbles; and if shaken for a while in a close stopt phial, and the phial is suddenly opened before the commotion ceases, they displode an elastic vapour with an audible noise, which shows that they abound in fixed air. At the fountain they both have a brisk, pungent, chalybeate taste; but the cathartic water tastes bitterish, which is not usually the case with the *chalybeate*. They lose their chalybeate virtues by exposure, and also by keeping; but the cathartic water soonest. They both putrify by keeping; but in time recover their sweetness *.'

* Elliot, p. 234.

The

The properties of the cathartic and of the chalybeate ſpring are, as might naturally be ſuppoſed, very different. The former is uſeful in caſes of habitual coſtiveneſs; the latter in diſorders of relaxation and debility.

Spa, *in the biſhopric of Liege.*—' In and about this town there are ſeveral ſprings, which afford excellent chalybeate waters: and in Great Britain they are the moſt in uſe of any foreign mineral waters.

' The principal ſprings are, 1. The *Poboun*, or *Pouhon*, ſituated in the middle of the village;—2. *Sauviniere*, about a mile and an half eaſt from it;—3. *Groiſbeeck*, near to the Sauviniere;—4. *Tonnelet*, a little to the left of the road to the Sauviniere;—5. *Watroz*, near to the Tonnelet;—6. *Geronſtere*, two miles ſouth of the Spa;—7. *Sarts*, or *Niverſet*, in the diſtrict of Sarts;—8. *Chevron*, or *Bru*, in the principality of Stavelot;—9. *Couve*,—10. *Beverſee*,—11. *Sige*,—12. *Geromont*, all near Malmdy.

' The *Pouhon* is a ſlow deep ſpring, and is more or leſs ſtrong or gaſeous according to the ſtate of the atmoſphere. The gallon contains ten grains of chalk, thirty of magneſia, ten of natron, and five of aerated iron. It yields of fixed air one hundred and thirty-two ounce meaſures. It contains more iron than any of the other ſprings, and does not ſo ſoon loſe its gas. It is in its moſt perfect and natural ſtate in cold, dry weather. It then appears colourleſs, tranſparent, and without ſmell, and has a ſubacid chalybeate taſte, with an agreeable ſmartneſs: at ſuch times, if it is taken out of the well in a glaſs, it does not ſparkle; but after ſtanding a while,

while, covers the glafs on the infide with fmall air-bubbles; but if it is fhaken, or poured out of one glafs into another, it then fparkles, and difcharges a great number of air-bubbles at the furface. In warm, moift weather, it lofes its tranfparency, appears turbid or wheyifh, contains lefs fixed air, and is partly decompofed. A murmuring noife alfo is fometimes heard in the well. It is colder than the heat of the atmofphere by many degrees. It is fuppofed to contain the greateft quantity of fixed air of almoft any acidulous water; and confequently has a remarkable fprightlinefs and vinofity, and boils by mere warmth. This, however, foon flies off, if the water is left expofed; though in well corked bottles it is in a great meafure preferved. It is capable of diffolving more iron than it naturally contains, and thus becoming a ftronger chalybeate. This is owing to the great quantity of fixed air which it contains. For the fame reafon an ebullition is raifed in this water on the addition of acids, as they difengage its fixed air. It mixes fmoothly with milk, whether it is cold or of a boiling heat.

'Of the *Sauviniere* water, a gallon yields 6.5 grains of chalk, 4.5 of magnefia, two of natron, 3.5 of kali, 2.2 of aerated iron, and 108 ounce meafures of fixed air. At the well it has fomewhat a fmell of fulphur.

'*Groifbeeck.* The water is of the fame nature as the Sauviniere, but contains a fomewhat larger proportion of the feveral ingredients. It has a vitriolic tafte, and fomewhat of a fulphureous fmell.

'*Ton-*

'*Tonnelet.* This is one of the most sprightly waters in the world. It is much colder than either of the other Spa waters; has no smell; is bright, transparent, and colourless; and from the rapidity of its motion does not foul its bason. It has a smart, subacid, sprightly taste, not unlike the briskest Champaign wine. From a variety of experiments it appears, that this water is more strongly charged than any of the others with fixed air, on which the *energy* of all waters of this kind principally depends, but it parts with it more readily. It contains more iron than any of the springs, except the Pouhon.

'*Watroz.* Its situation is lowest of any of the springs about Spa, and it is more apt to be foul: but when the well is cleaned out, and the water pure, it is found to be of the same nature as that of Pouhon. It is not cathartic, as some have asserted.

'*Geronstere.* This water has much less fixed air than the Pouhon. It has a sulphureous smell at the fountain, which it loses by being carried to a distance. This smell is strongest in warm moist weather. The air, or vapour, of this water affects the heads of some who drink it, occasioning a giddiness, or kind of intoxication, which goes off in a quarter or half an hour. The Pyrmont, and several other brisk chalybeate waters, are found to have the same effect. It is colder than any of the springs, the Tonnelet excepted.

'*Sarts,* or *Niverset.* It resembles the Tonnelet water, but is rather less brisk and gaseous. It is however more acid and styptic.

'*Bru*, or *Chevron*. The phyſicians at Liege have artfully decried this water, becauſe it is not in the principality of Liege. But by every trial it appears not much inferior to any of the Spa waters. In the quantity of fixed air and of iron it contains, it approaches the Pouhon.

'*Couve* and *Beverſee*. The Couve nearly reſembles the Tonnelet water; or rather, may be placed in a medium between that and the Watroz. It hardly equals the tranſparency, ſmartneſs, and generous vinous taſte of the firſt, but it greatly ſurpaſſes the latter. The Beverſee agrees with this, only that it does not retain its ſmartneſs ſo well by keeping.

'*La Sige*. It has ſome of the general properties of the Spa waters, but in other reſpects it is different. It is moderately ſubacid, ſmart, and grateful, but has no ſenſible chalybeate taſte. It ſparkles like Champaign when poured from one glaſs to another. Upon ſtanding it loſes its fixed air, and throws up a thick mother-of-pearl coloured pellicle. It is much more loaded with earthy matters, and leſs impregnated with iron and fixed air, than the other Spa waters.

'*Geromont*. As a chalybeate and acidulous water it ſeems to be nearly of the ſame ſtrength with La Sige; but it contains a greater quantity of natron, together with a mixture of ſea ſalt. The earthy matters, however, are leſs.' It appears, that theſe waters are compounded of nearly the ſame principles, though in different proportions. All of them abound with *fixed air*. They contain

tain more or leſs iron, natron, and calcareous and ſelenitical earths; together with a ſmall portion of ſea ſalt. Theſe are all kept ſuſpended, and in a neutral ſtate, by means of the aerial acid, or fixed air. From a review of the contents of theſe waters. it cannot be imagined that their virtues principally depend on the ſmall quantity of *ſolid* matters which they contain. They muſt therefore depend moſtly on their *fixed air*. And they are probably rendered more active and penetrating both in the firſt paſſages, and alſo when they enter the circulation, by means of that ſmall portion of iron, earth, ſalt, &c. with which they are impregnated*.

After all that has been alleged in favour of mineral waters, it muſt be confeſſed that their medical virtues are at beſt rather dubious. With reſpect to the metallic ſalts which they may contain, the quantity is too minute to be very efficacious in obſtinate complaints; and the warm baths have probably no other effect than a quantity of common water heated to the ſame temperature would have, if applied by means of an artificial bath at home. Where good effects have been wrought upon a patient's reſorting to a mineral water, phyſicians have overlooked the excellent conſequences which in the common courſe of things might be expected from the exerciſe of the journey, the change of air, and change of ſcene, from cheerful company, and, though laſt, not leaſt, perhaps, from the imagination of the patient.

* See Elliot, p. 249, &c.

APPENDIX.

# APPENDIX.

## TABLE OF SPECIFIC GRAVITIES.

| | |
|---|---|
| DISTILLED water | 1000 |
| Calcareous Earth | 2723 |
| Magneſian earth | 2155 |
| Barytic earth | 3973 |
| Argillaceous earth | 1669 |
| Siliceous earth | 2650 |
| Bottle glaſs | 2732 |
| White glaſs | 2892 |
| Flint glaſs | 3329 |
| Seves porcelain | 2145 |
| China ditto | 2384 |
| Lime ſtones, from | 1386 |
| ——— to | 2390 |
| Common ſlate | 2672 |
| Muſcovy talk | 2792 |
| Calcareous ſpar | 2715 |
| Fluor ſpar | 3180 |
| White marble | 2716 |
| Diamond | 3445 |
| Ruby | 4283 |
| Topaz | 3460 |
| Emerald | 3600 |
| Hyacinth | 3764 |
| Garnet | 3978 |
| Tourmaline | 3050 |
| Opal | 2764 |
| Cat's eye | 2240 |
| Onyx | 2600 |
| Carnelion | 2704 |
| Common flint | 2700 |
| Jaſper | 2778 |
| Quartz | 2654 |
| Agate | 2590 |
| Gold | 19640 |
| Platina | 22000 |
| Mercury | 13568 |
| Lead | 11352 |
| Silver | 10474 |
| Copper | 8878 |
| Iron | 7788 |
| Tin | 7299 |
| Biſmuth | 9823 |
| Nickel | 8660 |
| Arſenic | 5763 |
| Zinc | 7191 |
| Antimony | 6702 |
| Manganeſe | 6850 |
| Cobalt | 7811 |
| Tungſtein | 6066 |
| Molybdena | 4738 |
| Vitriolic acid | 2472 |
| Nitrous acid | 1682 |
| Muriatic acid | 1085 |
| Fluor acid | 1500 |
| Oil of olives | 915 |
| Linſeed oil | 940 |
| Burgundy wine | 991 |
| Bourdeaux ditto | 993 |
| Malmſey madeira | 1038 |
| Cyder | 1018 |
| Woman's milk | 1020 |
| Mare's milk | 1034 |
| Cow's milk | 1032 |
| Goat's milk | 1034 |
| Ewe's milk | 1040 |
| Elaſtic gum | 933 |
| Naptha | 708 |
| Camphor | 989 |
| Spermaceti | 943 |
| Tallow | 942 |
| Vitriolic æther | 739 |
| Nitrous æther | 909 |
| Muriatic æther | 730 |
| Acetous æther | 866 |
| Pureſt ſpirit of wine | 820 |

TABLE

TABLE of the weights of the different gasses at 29. 84. English inches, barometrical pressure, and at 54. 5° of temperature, according to Fahrenheit's thermometer, expressed in English measure, and English troy weight. From Lavoisier's Chemistry.—The weight of the five first were ascertained by M. Lavoisier himself; the last three were inserted by M. Lavoisier on the authority of Mr. Kirwan.

| Names of gasses. | Weight of a cubical inch. | Weight of a cubical foot. | | |
|---|---|---|---|---|
| | | oz. | dr. | grs. |
| Atmospheric air - | . 32112 | 1 | 1 | 15 |
| Azotic gas - - - - | . 30064 | 1 | 0 | 39 . 5 |
| Oxygen gas - - | . 34211 | 1 | 1 | 51 |
| Hydrogen gas - - | . 02394 | 0 | 0 | 41 . 26 |
| Carbonic acid gas - | . 44108 | 1 | 4 | 41 |
| Nitrous gas - - - - | . 37000 | 1 | 2 | 39 |
| Ammoniacal gas - | . 18515 | 0 | 5 | 19 . 73 |
| Sulphureous acid gas | . 71580 | 2 | 4 | 38 |

END OF THE SECOND VOLUME.